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MEASUREMENT OF SONAR RANGE EMPLOYING GRAPHIC INDICATOR METHODS

[UNCLASSIFIED TITLE]

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ABSTRACT

The Sonar Graphic Indicator in conjunction with a standard echo-ranging sonar provides range rate by doppler measurements. It also provides discernible discrimination because of phase coherence or doppler difference between the hull echo of the target and reverberation or wake return. To utilize these features for more accurate sonar range measurements, an experimental equipment has been constructed. This equipment consists of a Graphic Indicator with strip display and a range unit providing digital range indication and rate-aided range tracking.

The range unit consists of an electronic chronometer which measures the time interval between the projected sonar pulse and the appearance of an electronic range cursor which can be positioned in coincidence with the hull echo in the strip display. Range rate obtained from the Graphic Indicator is utilized to give rate-aided tracking by automatically positioning the cursor.

Evaluation tests of the experimental equipment were conducted using a destroyer and target submarine. The vessels participated in a series of maneuvers designed to present the target at all aspects for a number of combinations of speed, depth, range, range rate, and range acceleration. Approximately 100, 000 items of data including range, range rate, bearing, ship's speed, aspect, and other variables were photographically recorded.

Data obtained from these tests yielded information as to the accuracy of range mesaurement by the Sonar Graphic Indicator method, and produces evidence leading to a better understanding of a submarine as a sound reflector. Analysis of data indicated the experimental equipment capable of measuring range with an average error of less than one yard and an rms error of approximately 12 yards. It was also observed that rate-aided tracking considerably enhanced the operator's ability to track the target in range.

The analysis of range data as a function of target aspect permitted the development of an acoustic model of the submarine, a reflecting body approximately 62 yards in length with a lateral dimension of 5 yards.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

AUTHORIZATION

NRL Problem S05-04
Project Nos. NR 585-040 and NE 060-909

Manuscript submitted August 31, 1955

MEASUREMENT OF SONAR RANGE EMPLOYING GRAPHIC INDICATOR METHODS [UNCLASSIFIED TITLE]

INTRODUCTION

Initial sea tests of the Sonar Graphic Indicator[1] demonstrated its ability to provide discernible discrimination between the echo from the hull of a submarine and distracting returns from other sources. Such distracting returns usually consist of submarine wake echoes, and reverberations and returns from disturbances in the medium such as knuckles. This discrimination is achieved in two ways: (a) by displaying doppler differences between the various returns, and (b) by displaying phase coherence which is usually greater for the hull than for other sources. Thus, the increment of range occupied by the target can be well defined. In addition, the precise measurement of doppler shift yields the range rate of the target.

In order to take advantage of this enhanced hull discrimination in the measurement of accurate sonar ranges, the Laboratory constructed equipment employing the features of the original Sonar Graphic Indicator, the improved display (strip display),[2] and a range unit utilizing the measured range rate to provide rate-aided range tracking. The outputs from the equipment were range and range rate.

The experimental equipment was tested at sea in the USS SAUFLEY (EDDE-465) during 19-23 October 1953 in the Key West Area, under Assist Project Bu/S221/S67, Phase II.

The purpose of these tests was twofold: (a) to demonstrate the accuracy of range measurement by the Graphic Indicator method, and (b) to acquire data leading to the better scientific understanding of a submarine as a sound reflector. The tests were planned and conducted to encompass as many of the combinations of variables experienced in sonar operations as practically possible.

EQUIPMENT

Experimental Equipment

The Sonar Graphic Indicator equipment was installed in USS SAUFLEY during 16-18 October 1953. The experimental instrumentation consisted of a Graphic Indicator receiver with a strip display and a range unit. The range unit was designed for the precise measurement of transit time of the sonar signal from the projector to the target and return.

Figure 1 is a simplified block diagram of the experimental equipment. The sonar signal was taken from the output of the audio-scan switch of the ship's SQS-11 sonar equipment. This was processed by the Graphic Indicator receiver to provide the Z-axis modulation for forming the pattern on the strip display.

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[1] Asbury, G. F., Sr., Dixon, T. O., Hurdle, B. G., Mackey, R. J., Jr., and Kohn, E. J., "The Sonar Graphic Indicator," NRL Secret Report No. 4028, 6 August 1952

[2] "Preliminary Instructions for Operation of Sonar Data Indicator, Units 2 and 3-$Q5_x$, NRL Memorandum Report 277 (Confidential), 1 March 1954

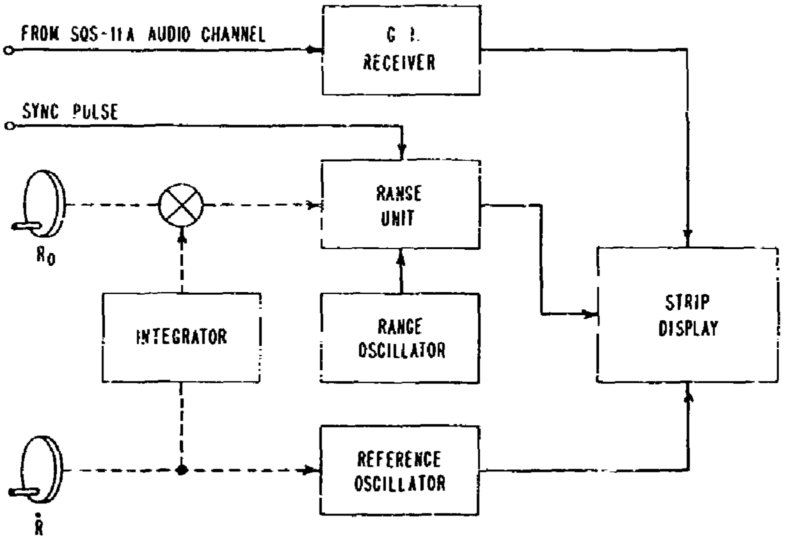

Fig. 1 - Simplified block diagram of the experimental Sonar Graphic Indicator equipment

The range unit consisted of an electronic chronometer which measured the time interval between the projected sonar pulse and the appearance of an electronic range cursor which was positioned in coincidence with the hull echo on the strip display. The chronometer measured the elapsed time digitally in increments arranged to be equal to the time required for one yard of two-way sound propagation, thereby producing a one-to-one correspondence between the number of elapsed time increments and yards of range. The timing mechanism was an oscillator having a period equal to the elapsed time increment. The frequency of this (range) oscillator was adjustable to correct for sound propagation velocity variations due to changes in water temperature. A decade electronic counter counted the cycles of the range oscillator during the measured interval. A keying pulse from the sonar, designated "sync pulse" in the block diagram, was used to start the counters and thereby establish zero time for the measured interval. This pulse also was used to synchronize the range sweep of the strip display.

Range was displayed on a decade bank of lights. The lights indicated the positions of each of a set of four ten-position rotary switches which were cascaded in decade fashion. The switches served as range keepers to hold values of range generated by the range-rate integrator plus any range corrections set in by means of the hand crank labelled R_0. The counters, described above, would count the cycles of the range oscillator until they reached a count equal to that represented by the position of the range-keeper switches. When that count was reached, a coincidence circuit caused a pulse to be generated which produced a brightened vertical line (range cursor) on the strip display. In this manner the range cursor was caused to appear on the display at an accurately measured time after the occurrence of the transmitted pulse. The length of this time interval would be equal to the time required for two-way sound propagation for the range set into the range-keeper switches. Positional coincidence of the range cursor and target-echo trace on the strip display would indicate time coincidence of the echo and the range-cursor pulse. Therefore, when the range cursor appeared in coincidence with the target-echo trace, the range set into the range-keeper switches represented the true echo range to the target.

In order to track a target in range it was necessary to keep the range cursor in coincidence with the target-echo trace. This was done by a combination of automatic and manual controls; that is, by combining in a differential (Fig. 1) the output of a range-rate integrator giving continuous rate-aided tracking, and the manual R_0 control. Rate-aided tracking enables the displayed range to keep pace with the actual range automatically, and necessitates only initial positioning and occasional minor corrections to be applied by the R_0 control.

The measured range rate is obtained from the Graphic Indicator in the usual manner, that is, by adjusting the reference oscillator at each ping with the $\dot{R}$ control so as to produce a horizontal echo pattern on the display. The shaft position of the $\dot{R}$ control is then a measure of range rate. Technical details of the equipment are contained in Appendix A.

Other Equipment

Standard equipment employed in the ship for these tests were the AN/SQS-11A Sonar, OKA-1 Resolving Equipment, Mark 25 Radar, Mark 37 Gun Director, Bathythermograph equipment, Dead Reconing Tracer, and Gyrocompass. Special equipment employed in the ship were the Target Locator, Data Panels, and photographic equipment. Standard equipment employed in the target submarines consisted of the WFA or WDA Sonar, the periscope, the JT Sonar, Gyrocompass, BT, and periscope radar. Special equipment in the submarines included the Target Locator Transponder and a Sonar Graphic Indicator (operated passively).

One of the most important requirements for these tests was an equipment, to serve as a standard, capable of precise measurement of range between specific positions on the surface vessel and the target. The target locator developed at the Surface Anti-Submarine Development Detachment as a range standard for sonar equipment evaluation fulfilled this requirement. The sonar pulse transmitted by the SQS-11A sonar triggered a transponder in the target vessel. The transponder returned a pulse at a frequency 5 kc lower. A precision timing device measured the elapsed time, converted to range, between the outgoing pulse and the returned synthetic pulse. This interval gave a point-to-point range measurement between known positions on the surface vessel and the target.

MEASUREMENT PROCEDURES

Maneuvers for Tests

Maneuvers employed in the tests were designed to present the target at all aspects for a number of combinations of speed, depth, range, range rate, and range acceleration. The basic maneuver (Fig. 2(a)) was one in which the surface vessel passed the submarine on a parallel course. Runs based on this maneuver differed from each other with respect to minimum range, submarine speed, and depth. This maneuver provided a smoothly changing aspect, the rate of change depending on the relative velocities of the two vessels, and a wide variation of range rate. To provide a rapidly varying aspect superimposed upon the smoothly changing aspect, runs were made with the target submarine superimposing zigzag and sinuous variations upon the base course, as shown in Figs. 2(b) and 2(c). Rapidly changing target bearings were achieved by the surface vessel applying zigzag and sinuous variations to its base course. For a continuous variation of aspect, the submarine assumed a base course and a constant speed at periscope depth, and the surface vessel spiraled around the target at approximately constant range (Fig. 2(d)).

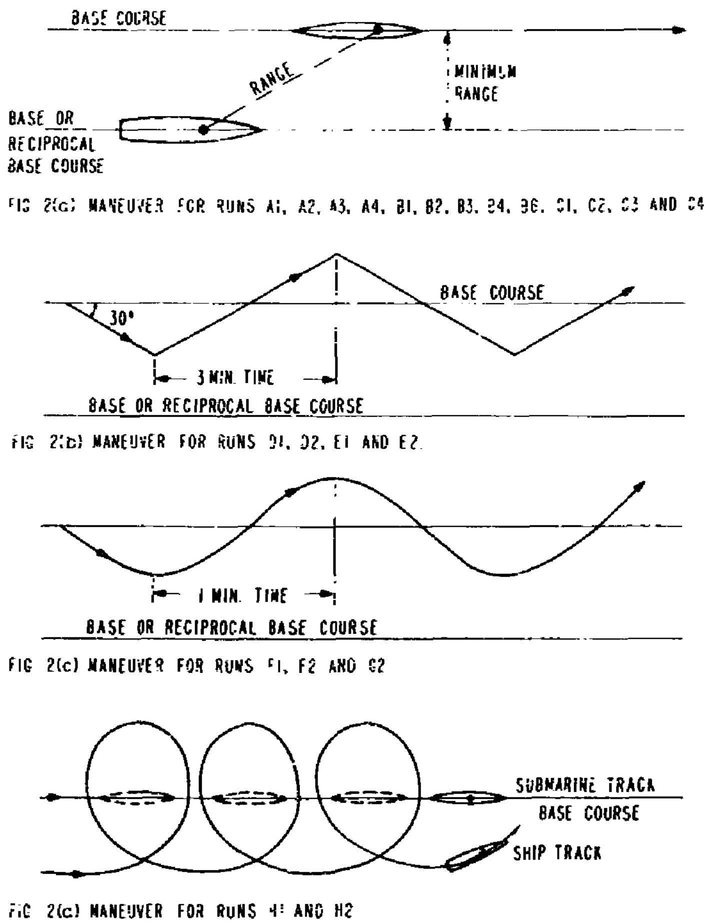

FIG 2(a) MANEUVER FOR RUNS A1, A2, A3, A4, B1, B2, B3, B4, B6, C1, C2, C3 AND C4

FIG 2(b) MANEUVER FOR RUNS D1, D2, E1 AND E2

FIG 2(c) MANEUVER FOR RUNS F1, F2 AND G2

FIG 2(c) MANEUVER FOR RUNS H1 AND H2

Fig. 2 - Geometry for vessel maneuvers

The operations provided variations of target submarine speed from 3 to 12 knots, depth from 58 (periscope depth) to 250 feet, and aspect through 360°. Surface vessel variations of speed between 4 and 20 knots, and variations of relative target bearing through 360° were obtained. Sonar ranges varied between 330 and 2000 yards. Table 1 summarizes the maneuver data for each run.

Environmental Conditions

The tests were conducted in an operating area approximately 30 miles south-southeast of Key West, Florida. Sea conditions varied between state one and three with an average for the tests between state one and two. Water depths varied between 350 and 600 fathoms, and water temperatures at the surface varied from 82.0° to 84.5°F. BT traces showed a "Mike" type pattern with the isothermal depth varying between 100 and 200 feet.

Equipment Operating Procedure

Upon detection of the target on the strip display, the operator adjusted his range-rate control to bring the target-hull echo trace to a horizontal position, thereby delivering the

TABLE 1
Summary of Maneuver Data

Run			Submarine *			Surface Vessel		Range	
Desig.	Date	Duration (min)	Course (deg's true)	Speed (knots)	Depth (ft)	Course (deg's true)	Speed (knots)	Min (yd)	Max (yd)
A-1	Oct. 20	67	140	3	58 (PD)	150	4-5	350	1600
D-1	Oct. 20	26	Zig, About 140	3	58 (PD)	150-155	12	550	1500
E-1	Oct. 20	22	280	3	58 (PD)	Zig, About 280	8-11	530	1450
F-1	Oct. 20	35	Sinuous, About 280	4	58 (PD)	280	5.5	440	1700
G-1	Oct. 20	42	130	4	58 (PD)	Sinuous, About 130	4-10	580	1650
B-1	Oct. 20	21	120	3	150	120	16-10	360	1400
C-1	Oct. 20	14	290	2	250	290	4-10	350	1500
C-2	Oct. 20	7	290	3	250	120-110	9-12	450	1400
B-2	Oct. 20	13	290	4	150	290	12-9	400	1300
A-4	Oct. 20	17	290	7	58 (PD)	290	10-16	500	1560
A-2	Oct. 21	10	160	4	58 (PD)	170	10	400	1400
A-3	Oct. 21	31	160	6	58 (PD)	160	10	400	1900
D-1	Oct. 21	11	Zig, About 160	4	58 (PD)	20-0-340	5	750	2000
D-2	Oct. 21	12	Zig, About 160	6	58 (PD)	160	10	700	1500
H-1	Oct. 21	43	160	3	58 (PD)	Spiral	10	820	1200
B-3	Oct. 21	28	280	6	150	280	10	400	1650
C-3	Oct. 21	7	280	5	250	100	8	400	1200
B-6	Oct. 21	8	280	5	150	280	20	400	1800
H-2	Oct. 21	20	280	5	58 (PD)	Spiral	9-16	430	1100
B-4	Oct. 22	22	150	12-4	150	150	6-20	370	1500
C-4	Oct. 22	12	150	8	250	133-150		400	1850
A-4	Oct. 22	14	060	8	58 (PD)	060-070	15-20	540	1400
D-2	Oct. 23	16	Zig, About 160	5.5	58 (PD)	150-161	10-15	340	1480
E-2	Oct. 23	18	160	6	58 (PD)	Zig, About 160	10 5-15	600	1650
X-1	Oct. 23	22	Evasive	Two Simulated			15-20	30	1570
X-2	Oct. 23	22	Evasive	Attack Runs			15-20	30	1570

*Target submarine employed on 20th, 21st, and 23 of Oct., USS BARB (SS220); on 22nd of Oct., USS QUILLBACK (SS424) range rate to the dial and to the integrator for the rate-aided range tracking. The range cursor was then brought into coincidence with the leading edge of the hull signature by first slewing it to approximate position with the slew control R_0', and then adjusting the fine control R_0. As tracking progressed, the operator corrected the range-rate control after each target return to keep the hull presentation horizontal. When the range rate was tracked accurately, the rate-aided tracking moved the range cursor in coincidence with the target trace and required no correction with the R_0 control. Occasionally the range cursor would move out of coincidence with the leading edge of the hull trace and a correction of several yards would have to be made with the R_0 control.

Data Recorded

Table 2 summarizes the data recorded for the exercises. The table lists the variable, the instrument from which the data were obtained, the recording interval, the means of recording, and the vessel in which the recording was made. The major portion of the data was recorded automatically during each ping interval with the ping repetition period varying between one and two seconds.

Time synchronization was accomplished by radio time checks between the ship and submarine prior to the start of operations each day. A standard ship's clock in Underwater Battery Plot was checked with the ship's master chronometer prior to operations each day. Data panel clocks were synchronized with the clock in UB Plot periodically during the exercises. Individual runs were started and stopped by underwater telephone communication from UB Plot.

RESULTS

Range Standard

One of the most important requirements of these tests was a range standard capable of precise measurement of range between specific positions on the surface vessel and the target. The target locator developed by the Surface Anti-Submarine Development Detachment as a range standard for sonar equipment was used for this purpose. Data obtained from the target locator was in most cases smooth and consistent; however, premature triggering by noise bursts caused the scattering of a number of range points, usually at a range shorter than the actual range. Even when some points were randomly scattered, there was a sufficient number along the actual range curve to make the true range easily recognizable (see Figs. 13 and 14).

It was intended that the Mark-25 Radar be used as a secondary standard in the measurement of range, but, although the radar had a tested range accuracy of ±5 yards, it developed that there were large and variable errors in the transmission of the radar range to the data panel, making this data unusable.

Sound Reflection as a Function of Target Aspect

Throughout the tests the echo range was measured from the leading edge of the transmitted pulse to the leading edge of the target signature as it appeared on the Graphic Indicator Strip Display. Physically this was a range measurement from the SQS-11A transducer to that area of the hull which produced the first recognizable echo. As previously described,

TABLE 2
Test Data Obtained

Variable	Instrument	Recording Interval	Recording Method	Vessel on which Recorded
Range (slant-std)	Target Locator	Every Ping*	Photographed on Data Panel	SAUFLEY
Range (slant)	Sonar OKA-1	Every Ping*	Photographed on Data Panel	SAUFLEY
Range	Radar Mark 25	Every Ping*	Photographed on Data Panel	SAUFLEY
Range (slant)	Graphic Indicator	Every Ping*	Photographed on Remote Indicator	SAUFLEY
Range Rate	Graphic Indicator	15 Seconds	Disc Recording†	SAUFLEY
Range Rate	Graphic Indicator	Variable	Written	BARB and QUILLBACK
Bearing (rel)	Optical Gun Director, Mark 37	Every Ping*	Photographed on Data Panel	SAUFLEY
Bearing (rel)	AN/SQS-11	Every Ping*	Photographed on Data Panel	SAUFLEY
Bearing (rel)	Target Locator	Every Ping*	Photographed on Data Panel	SAUFLEY
Bearing (rel)	Passive Sonar, JT	30 Seconds	Written	BARB and QUILLBACK
Bearing (rel)	Periscope	30 Seconds	Written	BARB and QUILLBACK
Course	Gryocompass	Every Ping*	Photographed on Data Panel	SAUFLEY
Course	Gryocompass	30 Seconds	Written	BARB and QUILLBACK
Speed	Pit Log	Every Ping*	Photographed on Data Panel	SAUFLEY
Speed	Pit Log	30 Seconds	Written	BARB and QUILLBACK
Signal	AN/SQS-11	Continuously	1st Channel of Magnetic Tape	SAUFLEY
Synchronizing Pulse	AN/SQS-11	Continuously	2nd Channel of Magnetic Tape Recorder	SAUFLEY
Water Temperature	Bathythermograph	Two or Three Times Daily	Bathythermogram	SAUFLEY, BARB, and QUILLBACK
Vessel Track	DRT	Every Run	Traced	SAUFLEY, BARB, and QUILLBACK

*Except for 8 runs that used 15-second intervals.

†Also included in these recordings were Graphic Indicator range, operator's names, sea states, operation plans, changes in own ship's speed, and qualitative bearing corrections.

the target locator measured the range from the SQS-11A transducer to the transponder-transducer on the target submarine. Since it was decided that the second periscope of the target submarine and the SQS-11A transducer on the surface vessel would be the reference points for the range analysis, it was necessary to refer all measured ranges to these points. Figure 3 presents the geometry of the ranges as measured by the Graphic Indicator equipment and by the Target Locator. Target aspect was known at all times from relative-bearing measurements made from the target submarine. Periscope range (standard range) can be readily computed by adding to the target locator range the range difference, a cosα, where a is the distance along the axis of the submarine between the transponder-transducer and the periscope, and α is the target aspect angle.

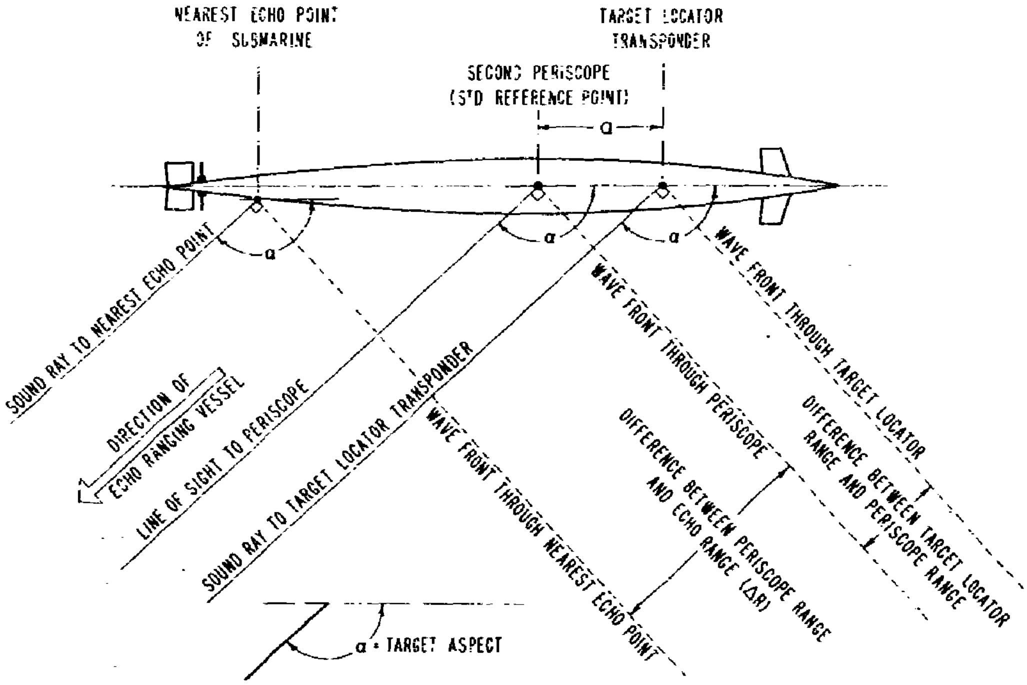

Fig. 3 - Geometry relating acoustic ranges to target

<u>ΔR vs. Aspect</u> - Referring the measured Graphic Indicator range to the second periscope requires a knowledge of the manner in which the sonar ping is reflected from the target hull. It is obvious that, in general, the periscope range and Graphic Indicator range will not be identical and their difference will be a function of aspect. The measured Graphic Indicator range will be shorter than the actual range to the periscope. In order to determine the shortening as a function of aspect, the difference, ΔR, between the measured Graphic Indicator range and the standard range (periscope range derived from Target Locator range) was plotted as a function of aspect. A range-vs.-aspect plot from a portion of a typical run is shown in Fig. 4, illustrating the method by which ΔR was obtained. In Fig. 5, a plot of ΔR vs. aspect, each point represents the average range difference (ΔR) for particular aspect angles as computed from the data of 11 runs. Since the aspect angle is repeated several times in some of the runs, as in spiral, zigzag, and sinuous runs, each ΔR point represents the average of 10 to 22 units of data except for the points at aspect angles of 0° and 180° which were determined from four and eight units, respectively.

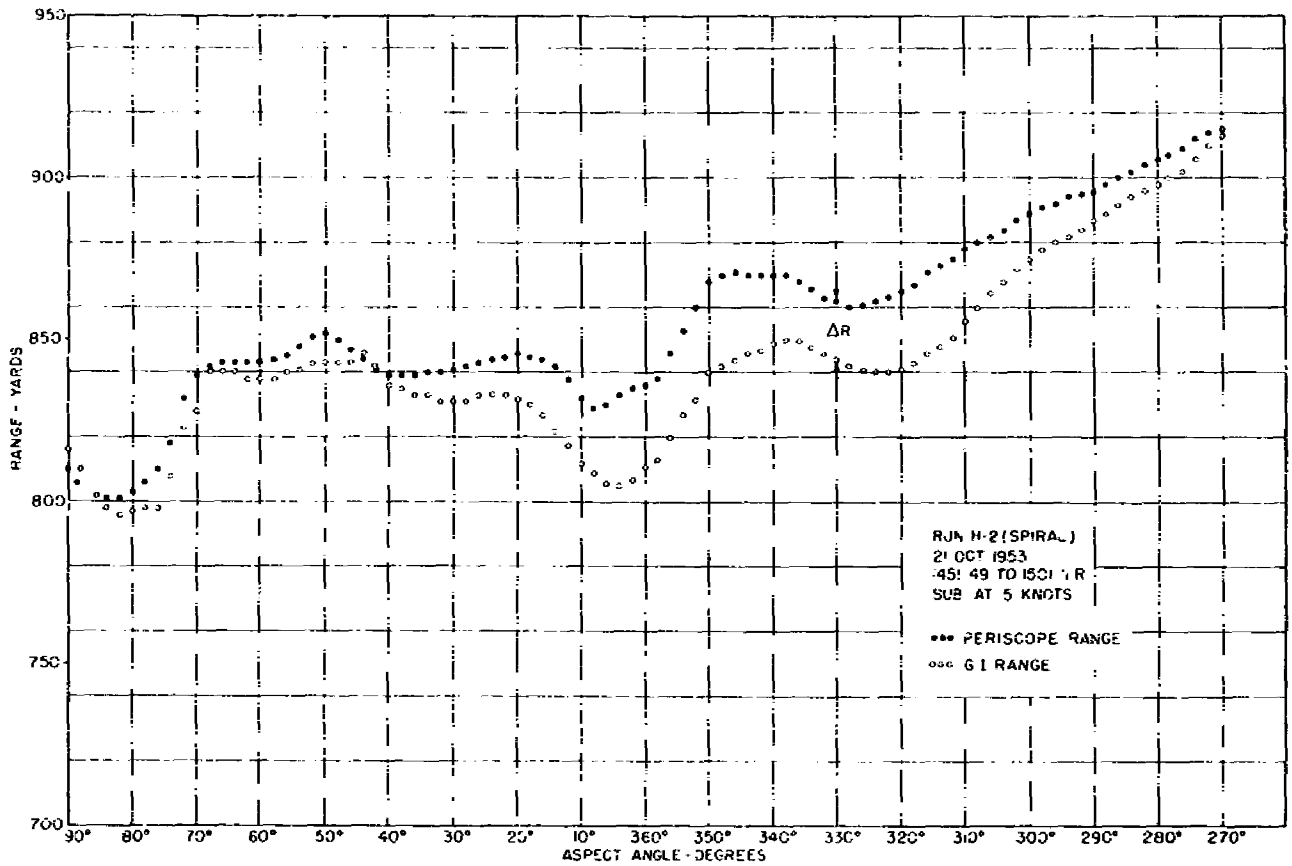

Fig. 4 - Range vs. aspect from portion of spiral-type run with periscope range derived from Target Locator range and Graphic Indicator range

Precision Indices of ΔR Data - The standard deviations are smallest near bow, beam, and stern aspects. Figure 6 shows the variations of the standard deviation and 90-percent confidence limit as functions of aspect. Of the four data points obtained at bow aspect, the largest value of ΔR was 33 yards and the smallest, 21 yards. The values of the eight points obtained at stern aspect varied between 34 and 43 yards. The small scatter of these points fixes, within narrow limits, the observed acoustical length of the target.

Position of Echo Point - The points, as plotted in Fig. 5, can be fitted closely to the curves of $2.5 + 23|\cos\alpha|$, where α is the aspect angle for bow-to-beam aspects, and $2.5 + 34.5|\cos\alpha|$ for stern-to-beam aspects. A plot of these functions has been fitted to the data in Fig. 7. This plot suggests the acoustic picture of a long, narrow target having two stationary reflectors (with respect to the hull), one 25.5 yards forward and the other 37 yards abaft the second periscope. These, however, are not necessarily the only reflectors. It is required only that one or the other be responsible for the leading edge of the echo. Figure 8 is a plot of the ΔR data (plotted in Fig. 7) minus 2.5 yards divided by the magnitude of the cosine of the aspect angle. This represents the apparent position of the nearest echo point along the keel line as a function of aspect. Since the cosine approaches zero at 90°, the accuracy with which the position of this point can be determined decreases as the aspect approaches abeam. All ranges measured in these tests were long enough (400 to 1500 yards) to permit considering the aspect angle being independent of the position on the submarine from which it is measured. It is significant that at beam aspects the Graphic Indicator range is shorter than the target locator range by an average of 3.5 yards with a 90-percent confidence limit of 2.5 yards. The 3.5-yard distance considered as a radius falls between the pressure and outer hull of the submarine. This result is in agreement with those expected from the postulated acoustic model and therefore serves as a check point for the remainder of the data.

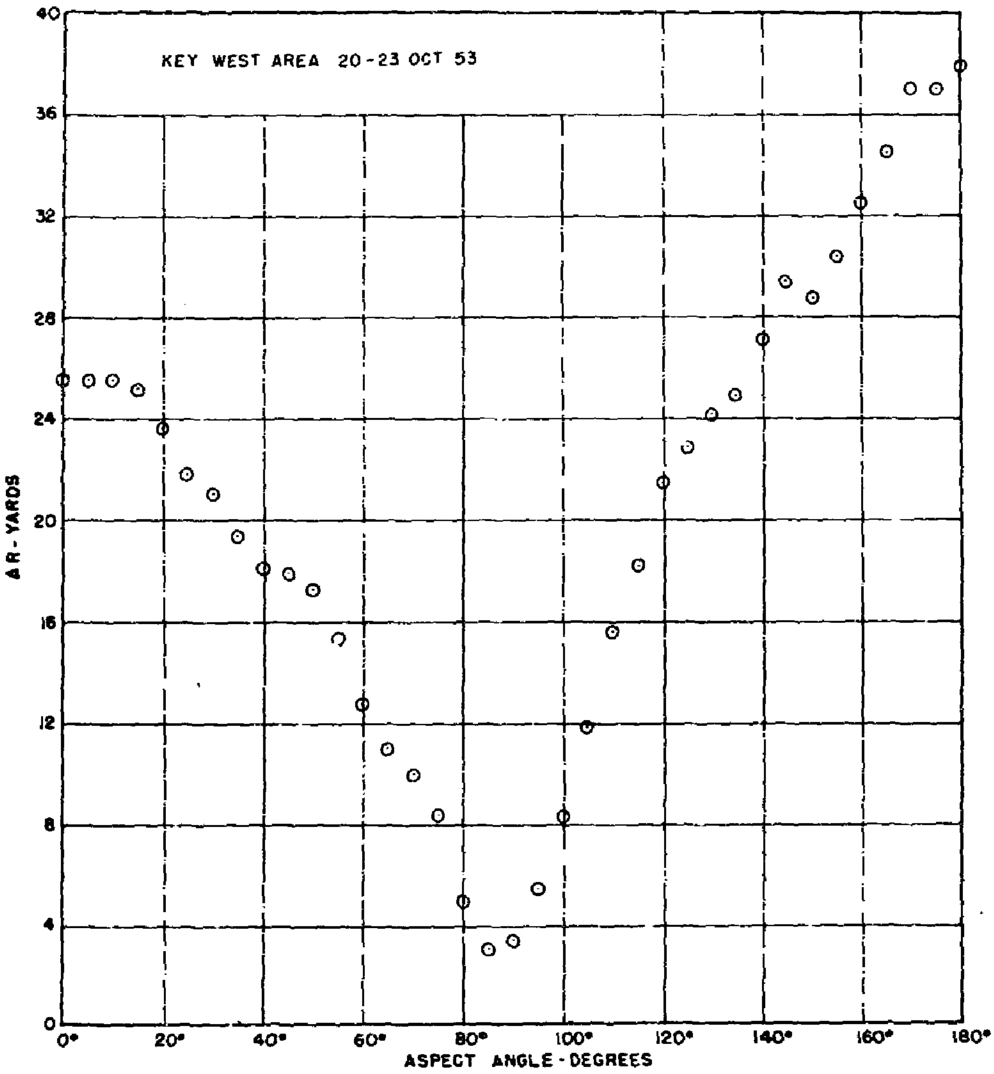

Fig. 5 - Average difference between range measured by Graphic Indicator and range to periscope as computed from Target Locator range as a function of aspect

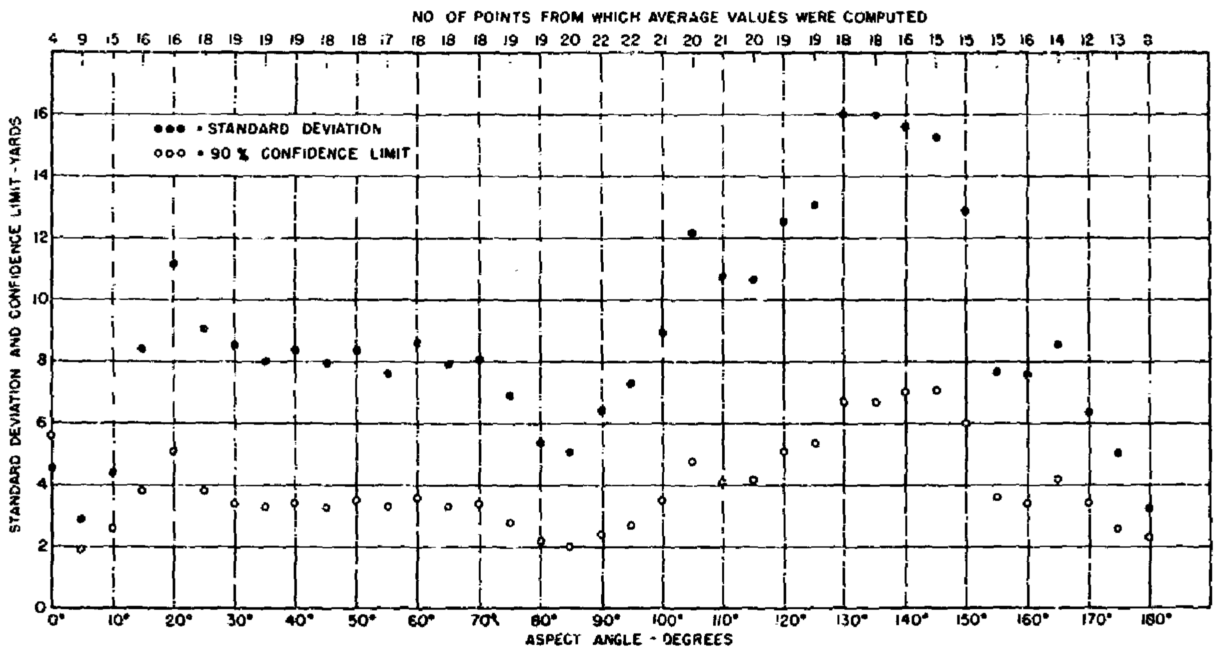

Fig. 6 - Standard deviation and 90-percent confidence limit for ΔR data

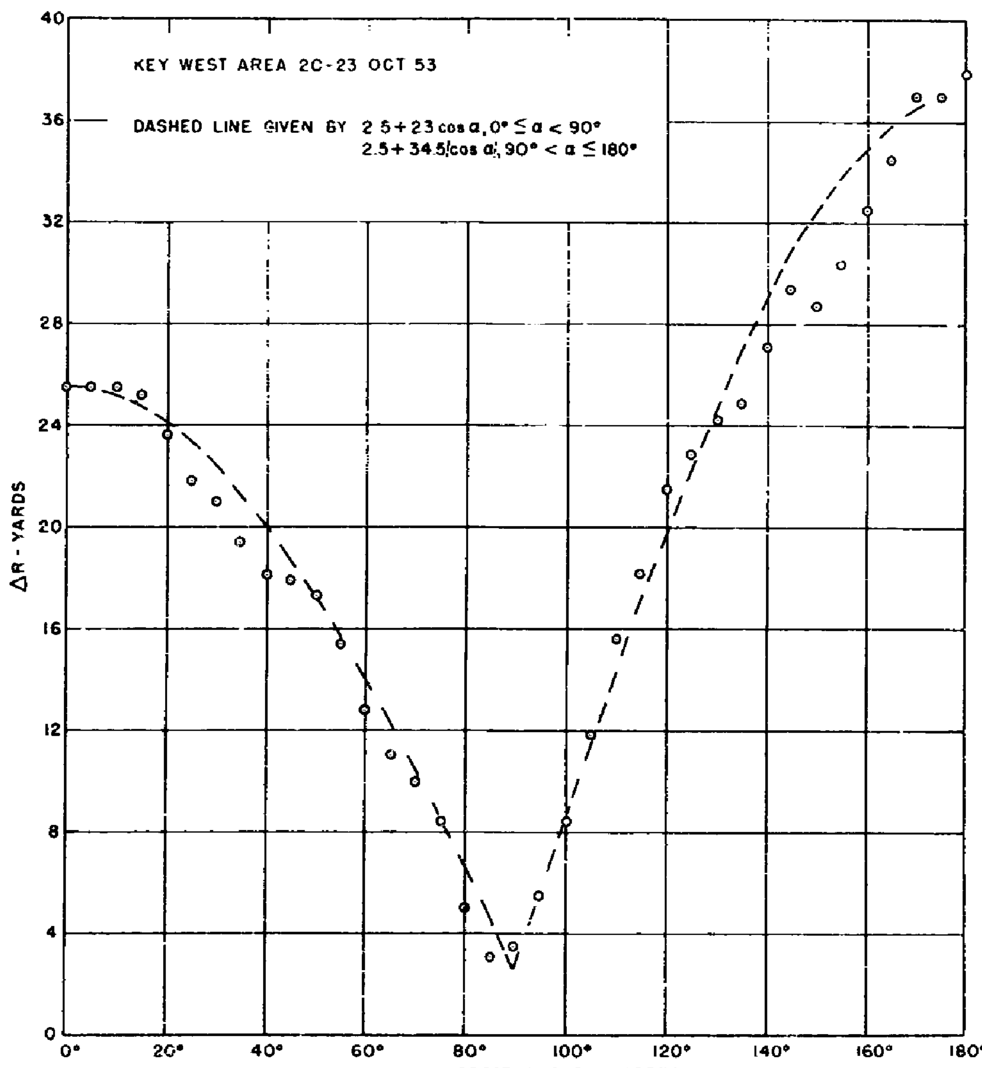

Fig. 7 - Difference between range measured by Graphic Indicator and range to periscope as computed from Target Locator range. Dashed line represents theoretical range difference for long, narrow target.

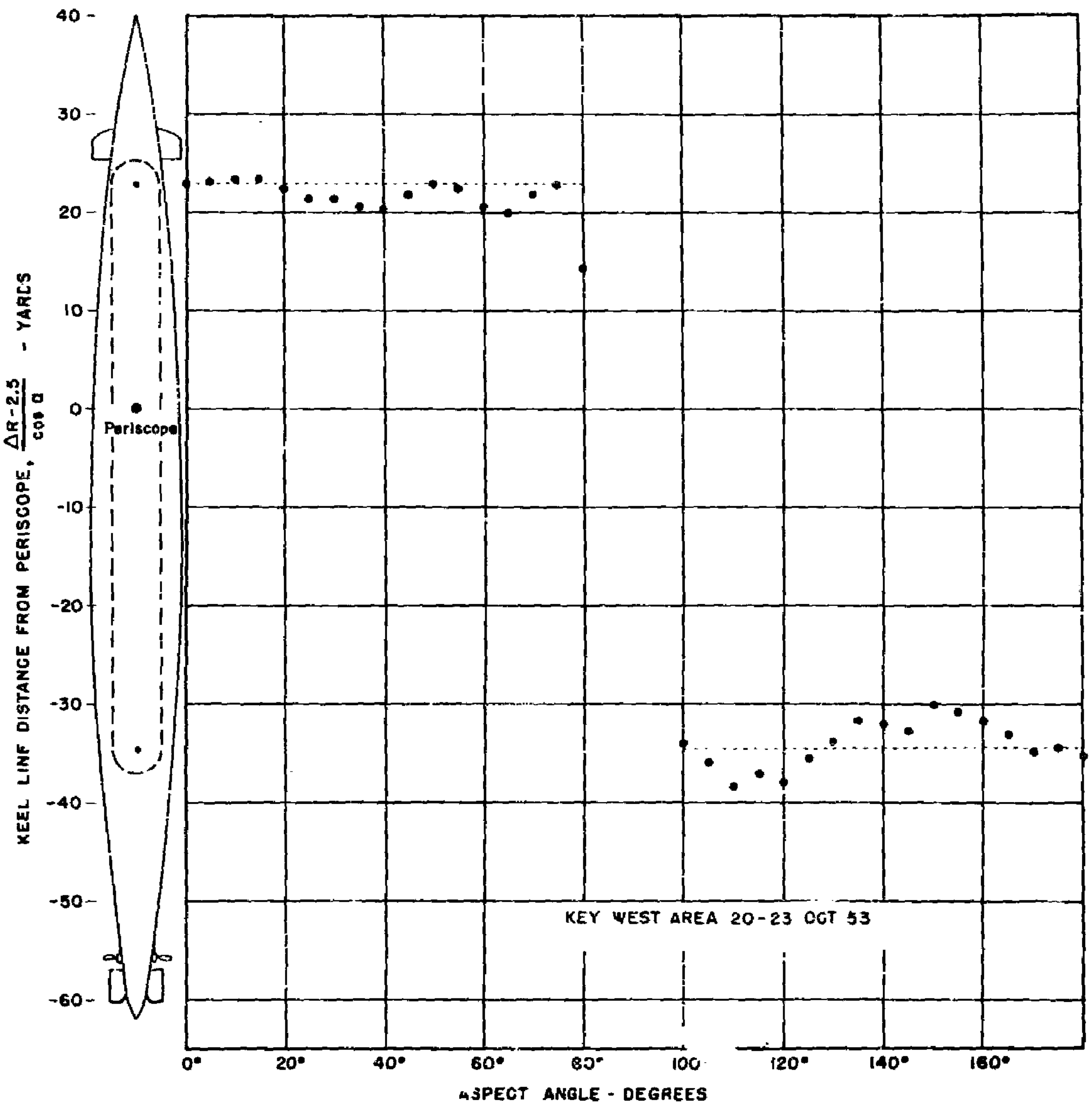

Fig. 8 - Position of postulated end reflectors on axis of submarine. Dashed line represents the postulated distance from periscope. The plotted points are obtained from measured values.

The apparent position of the reflection points as determined by this method depends upon the ability of the Graphic Indicator to detect the true leading edge of the echo. If a part of the leading edge is obscured by reverberation or wake return, the apparent initial echo point would move toward the center of the target, effectively shortening the acoustic length. One indication that the initial echo point did not shift toward the center of the target with increased wake or reverberation strength in these tests was found in a study of the echo-position variation as a function of target speed. Obviously, wake strength is a function of target speed but the echo position showed no significant variation with target speeds ranging from 3 to 12 knots. However, even if shortening occurred, the measured range would always be to a point on the target and not on the wake since the range is tracked to the leading edge of that part of the Graphic Indicator presentation which can be classified as target.

Acoustic Model of Target - Geometric considerations prohibit the accurate determination of the position of the nearest echo point along the submarine axis for beam or near-beam aspects. If the leading edge of the echo was always returned from the nearest point on the target, a long, narrow target would produce initial returns from one of two echo points, one at each end of the target and stationary with respect to the hull. For the case of a target with roughly hemispherical ends and for ranges which are long compared to the length of the target, the difference between the range to the nearest point on the target and the range to some fixed reference point on the target is given by

$\Delta R = r + d\,|\cos\alpha|$, where

r = radius of the hemispherical ends,

d = distance of the center of the end reflector from the reference point, and

α = aspect angle (Fig. 9).

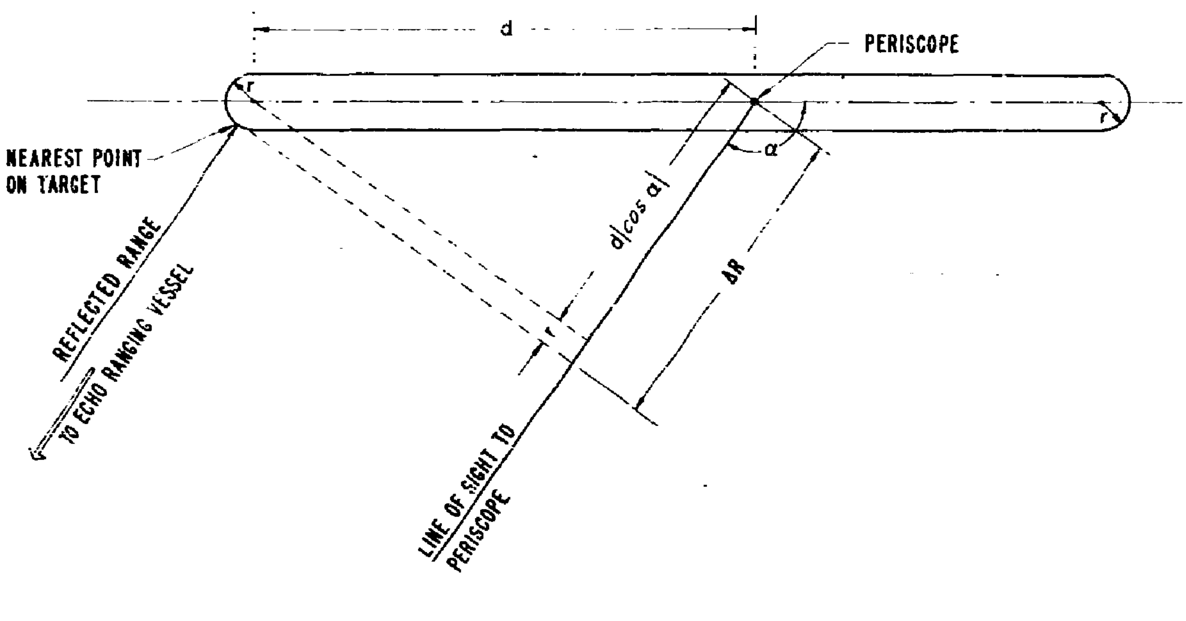

Fig. 9 - Postulated acoustic model of submarine

Except for near-beam aspects, if r is small, it can be absorbed in d, and then $\Delta R \simeq (r + d)|\cos\alpha| \simeq k|\cos\alpha|$. In the general equation, at $\alpha = 90°$, $\Delta R = r$, and from the data shown in Fig. 5, r is approximately 3 yards. The data of Fig. 5 are replotted in Fig. 10, along with the dashed curves 26 cosα and 36$|\cos\alpha|$, to illustrate the best fit of the simplified form, $k|\cos\alpha|$. The reflection points, as shown by the data, do not correspond with the physical extremes of the hull. The forward reflection point is approximately 26 yards forward of the second periscope or 14 yards from the bow. This point, then, is 3 yards aft of the forward end of the pressure hull. The other reflection point is approximately 36 yards aft of the second periscope or 27 yards from the stern. This point is at a position between the motors and the engine.

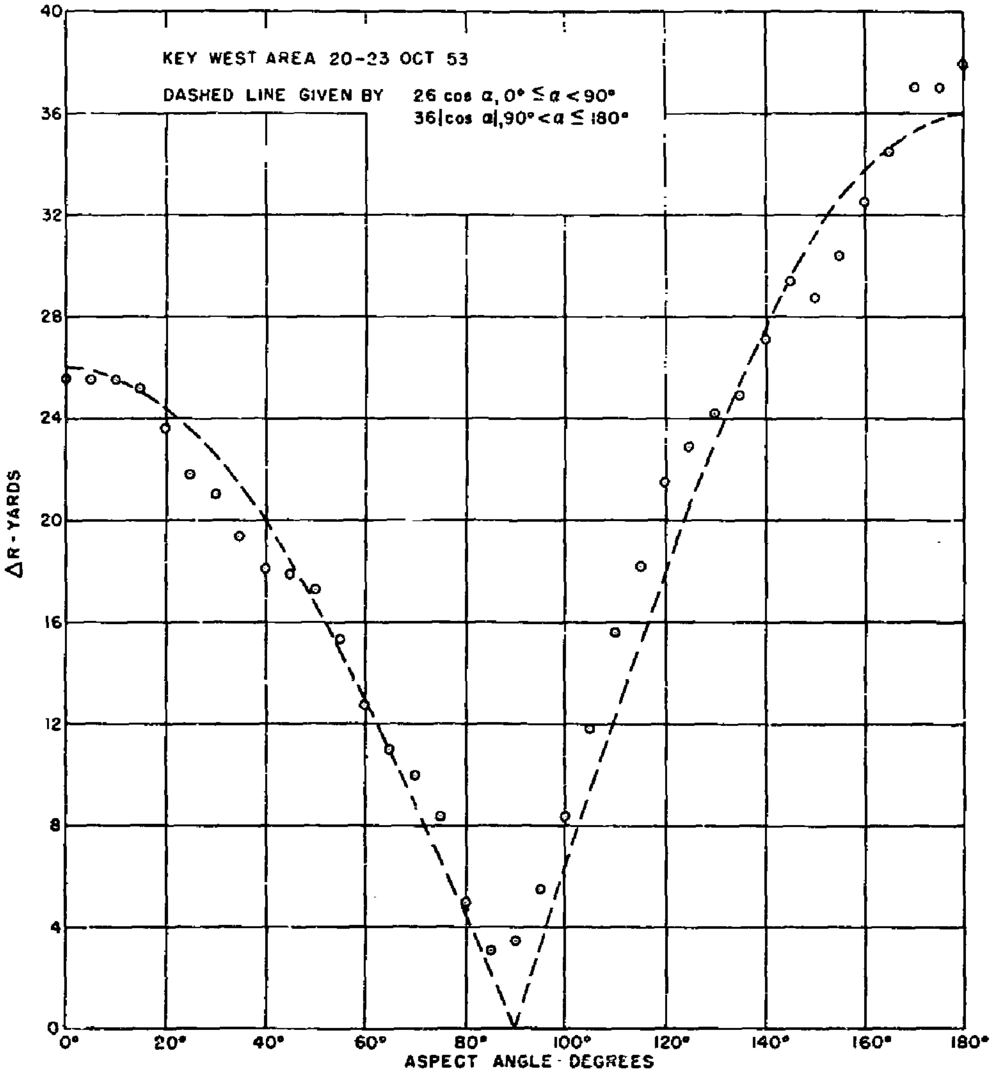

Fig. 10 - Aspect dependence of the difference between range measured by Graphic Indicator and range to periscope. Dashed line represents simplified theoretical range correction for long, narrow target.

Accuracy of Range Tracking

In order to determine the range tracking capabilities of the Sonar Graphic Indicator, it was necessary to compare its range measurements with those of the standard. This required that the Graphic Indicator measurements be referred to the periscope by adding the correction appropriate to the aspect, 26 $\cos\alpha$ for bow aspects, and 36$|\cos\alpha|$ for stern aspects. The OKA-1 operator tracked the leading edge of the sonar echo; therefore, in order to compare the OKA-1 range with the Graphic Indicator and target locator ranges, the same aspect corrections were applied to the range data obtained from the OKA-1. The range data from the three equipments, now corrected to measure range from the SQS-11A transducer in the surface vessel to the second periscope in the target submarine, were plotted as a function of time for each of the thirteen runs (Figs. 11 and 12). To avoid confusion, the periscope-range plot is given as a solid line in these two examples. The actual data points for the periscope range for these two curves are plotted in Figs. 13 and 14. The blank intervals in the data from the Graphic Indicator range unit for the F-1 plot were caused by an inability to read the synchronizing clock on the data film in those regions.

The range errors of the Graphic Indicator range unit and the OKA-1 range recorder were measured at intervals of 5 degrees of aspect in each run. Table 3 lists the rms and average errors as computed on a run basis.

The over-all rms and average errors, as computed on a point basis including all runs, are presented in Table 4. Average and rms errors were also computed at every 5 degrees of aspect including the data from all runs. In Fig. 15 the average error is plotted as a function of aspect, and the rms error is plotted similarly in Fig. 16. There is only a minor dependence of range error on aspect.

Within the compass of ranges included in this test there appears to be no dependence of range error on range. Average and rms errors were computed from the data of the thirteen runs processed, taking error measurements at equal intervals of range (every 50 yards) whereas the previous measurements had been taken at equal increments of aspect. These errors are plotted against range in Figs. 17 and 18. The over-all rms error taken from equal increments of range is 12.6 yards.

Since the Graphic Indicator used the listening beam of the SQS-11A transducer, trained by the sonar operator, the quality of the presentation was a function of the accuracy of train. If the sonar had a poor center bearing, the Graphic Indicator did not present a sharply defined picture of the target echo with respect to reverberation. Range was tracked to the leading edge of the echo and, although the target echo could be distinguished, it is felt that the lack of definition of the leading edge of the echo presentation was a major source of Graphic Indicator range error. This error should be decreased with improved bearing tracking.

Additional Observations

Measurement of range rate was not included in the purposes of this test; however, the range rate, as measured by the Graphic Indicator, was recorded at 30-second intervals. A comparison has been made between these range-rate values and these computed from the slope of the plot of target-locator range vs. time. The slope of the target-locator-range plot could be measured accurately only in those regions where the slope remained constant for 30 seconds or more. Data were taken from 24 such regions selected at random, and the rms error of the Graphic Indicator range rate was found to be of the order of one-half knot.

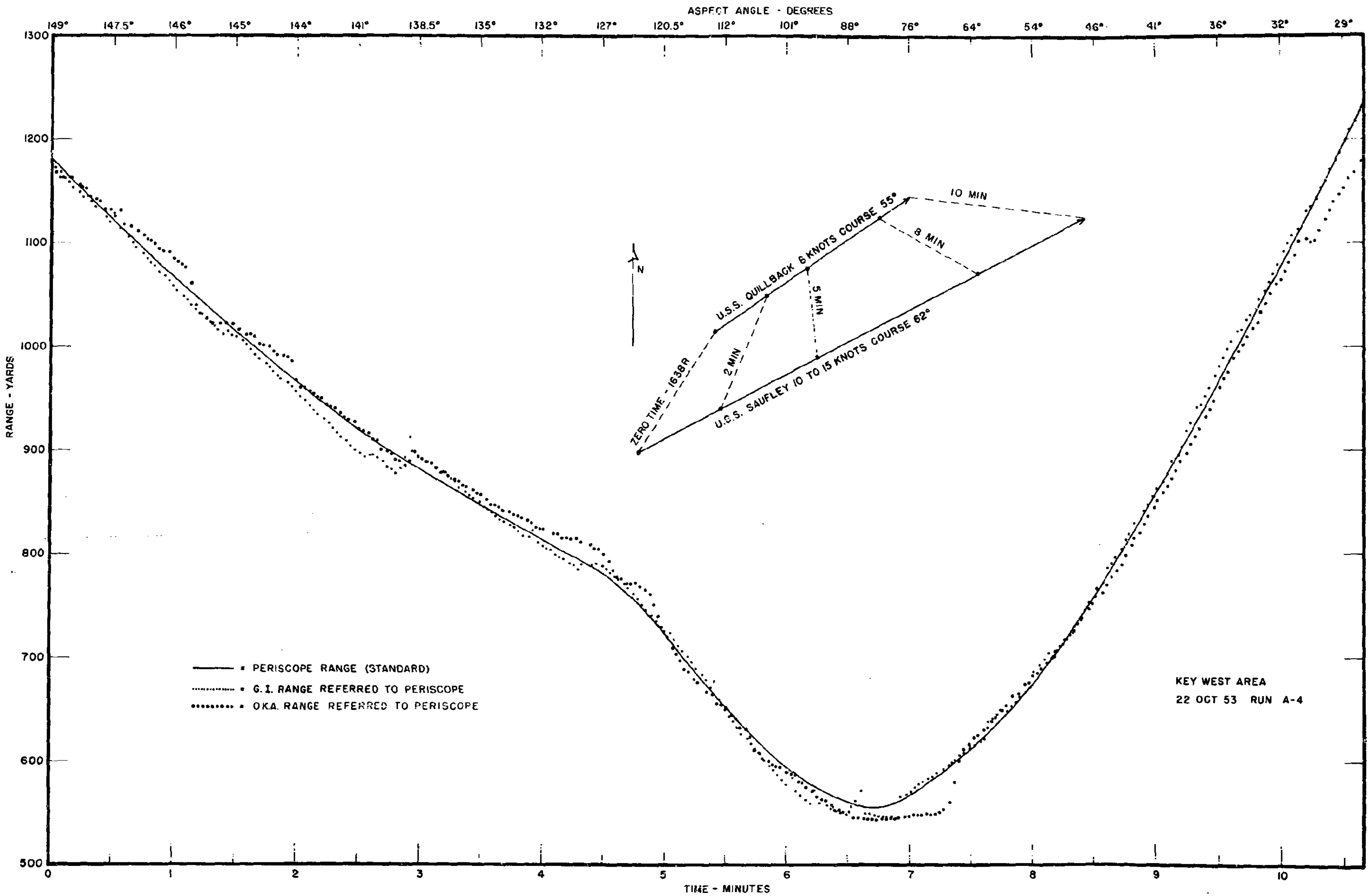

Fig. 11 - Range to target submarine measured simultaneously by three equipments in destroyer (Run A-4)

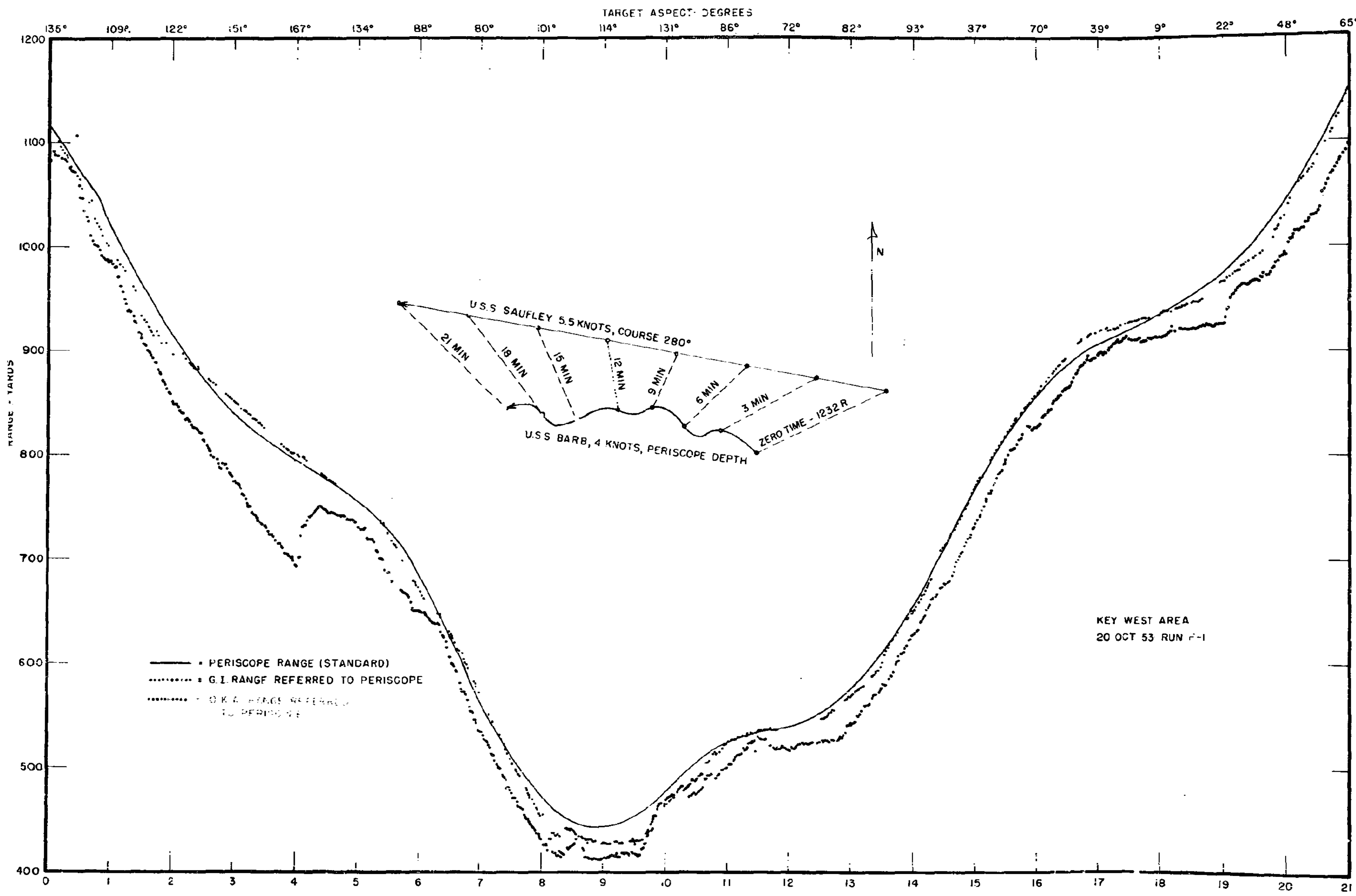

Fig. 12 - Range to target submarine measured simultaneously by three equipments in destroyer (Run F-1)

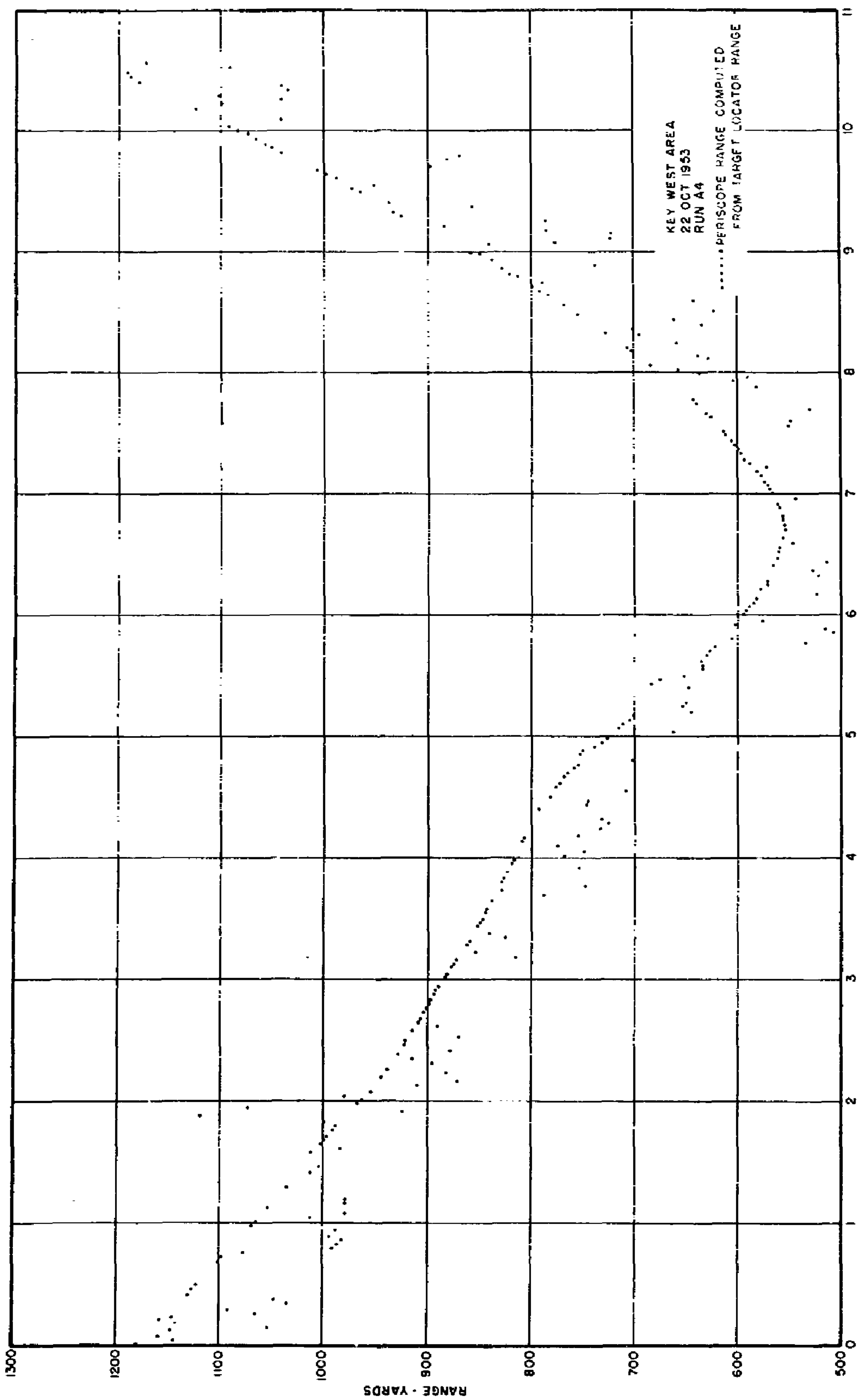

Fig. 13 - Range to submarine periscope (standard) computed from Target Locator range, as a function of time for run A-4

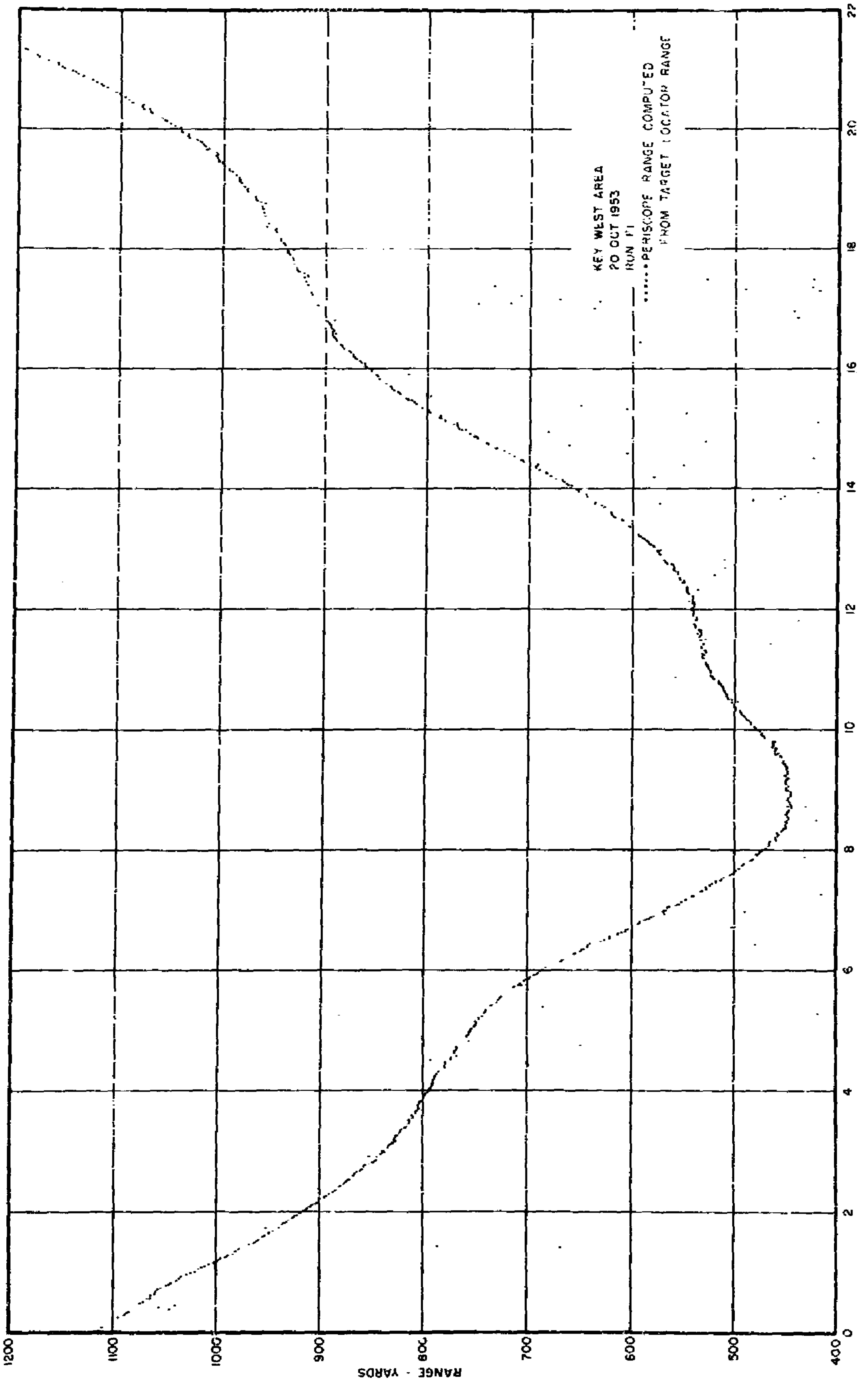

Fig. 14 - Range to submarine periscope (standard), computed from Target Locator range, as a function of time for run F-1

TABLE 3
Precision of Range Measurement Computed on a Run Basis

Run Designation	Date Oct.	Target Vessel	Target Speed (knots)	Target Depth (feet)	Type Run	Sonar Graphic Indicator Equipment		OKA-1	
						RMS Error (yards)	Avg Error (yards)	RMS Error (yards)	Avg Error (yards)
H-1	21st	BARB	3	58 (PD)	Surface Vessel Spiral	14.5	-3.2	35.2	-30.8
A-1	20th	BARB	3	58 (PD)	Parallel Course	10.7	-1.2	32.3	-2.7
E-1	20th	BARB	4	58 (PD)	Surface Vessel Zigs	13.2	-2.0	30.9	-27.2
F-1	20th	BARB	4	58 (PD)	Sub Sinuous	11.1	-4.9	40.8	-34.9
B-2	20th	BARB	4	150	Parallel Course	7.6	+0.4	32.0	-31.0
H-2	21st	BARB	6	58 (PD)	Surface Vessel Spiral	11.4	+5.5	19.0	-13.8
E-2	23rd	BARB	6	58 (PD)	Surface Vessel Zigs	11.2	-1.9	42.4	-32.4
D-2	23rd	BARB	6	58 (PD)	Sub Zigs	11.1	+2.1	61.1	-56.9
B-3	21st	BARB	6	150	Parallel Course	10.0	+1.7	28.0	-25.1
A-4	20th	BARB	7	58 (PD)	Parallel Course	5.4	-0.2	13.1	+7.9
A-4	22nd	QUILLBACK	8	58 (PD)	Parallel Course	7.0	+0.1	12.6	-2.7
C-4	22nd	QUILLBACK	8	250	Parallel Course	12.3	+8.3	36.7	+32.3
B-4	22nd	QUILLBACK	12	150	Parallel Course	13.5	-4.7	37.3	+35.3

TABLE 4
Accuracy of Range Measurement
Computed from Total Data

Equipment	RMS Error (yards)	Average Error (yards)
Sonar Graphic Indicator Equipment	11.8	-0.3
OKA-1	36.2	-23.4

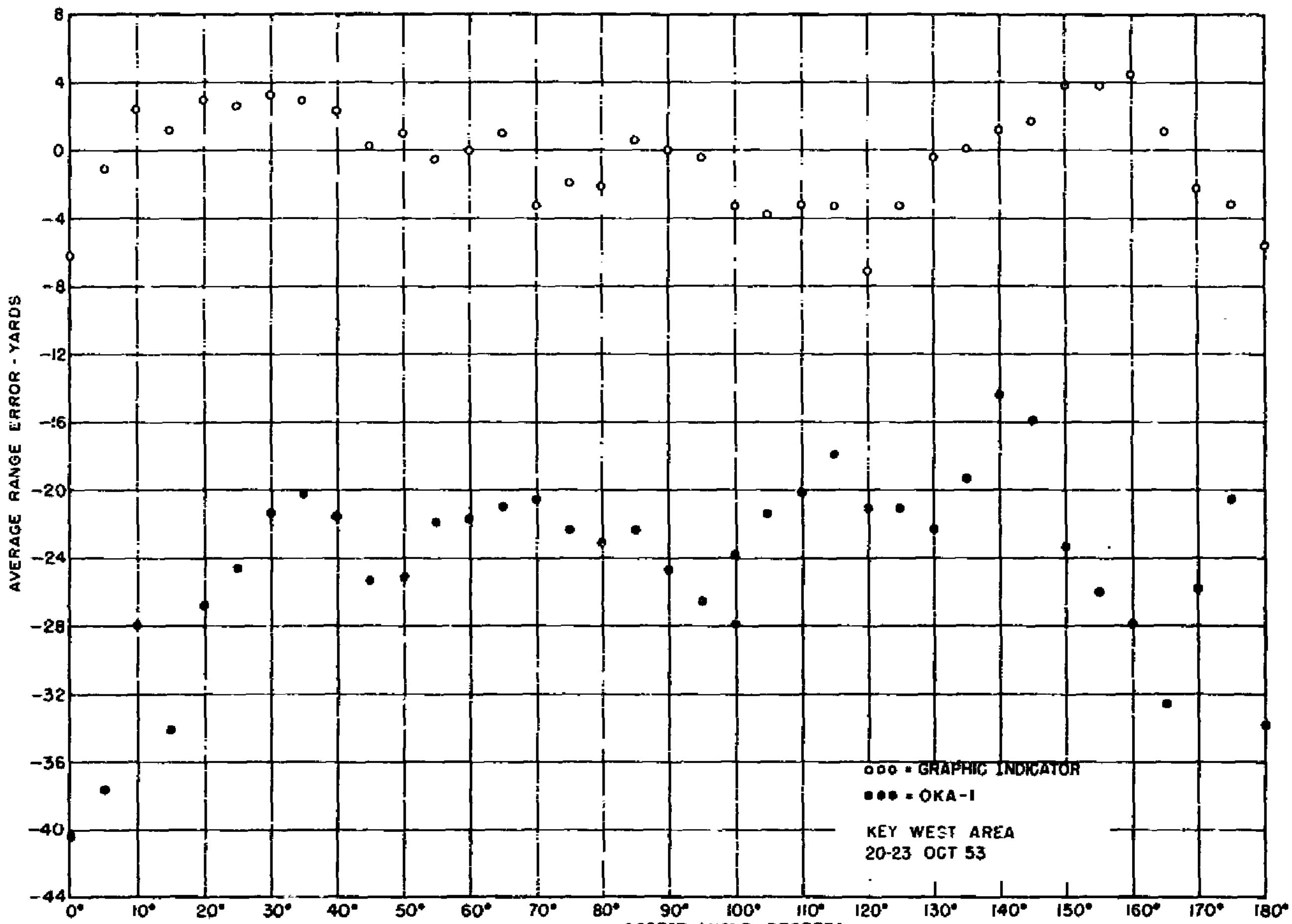

Fig. 15 - Aspect dependence of average-range error. Periscope range derived from Target Locator range as standard.

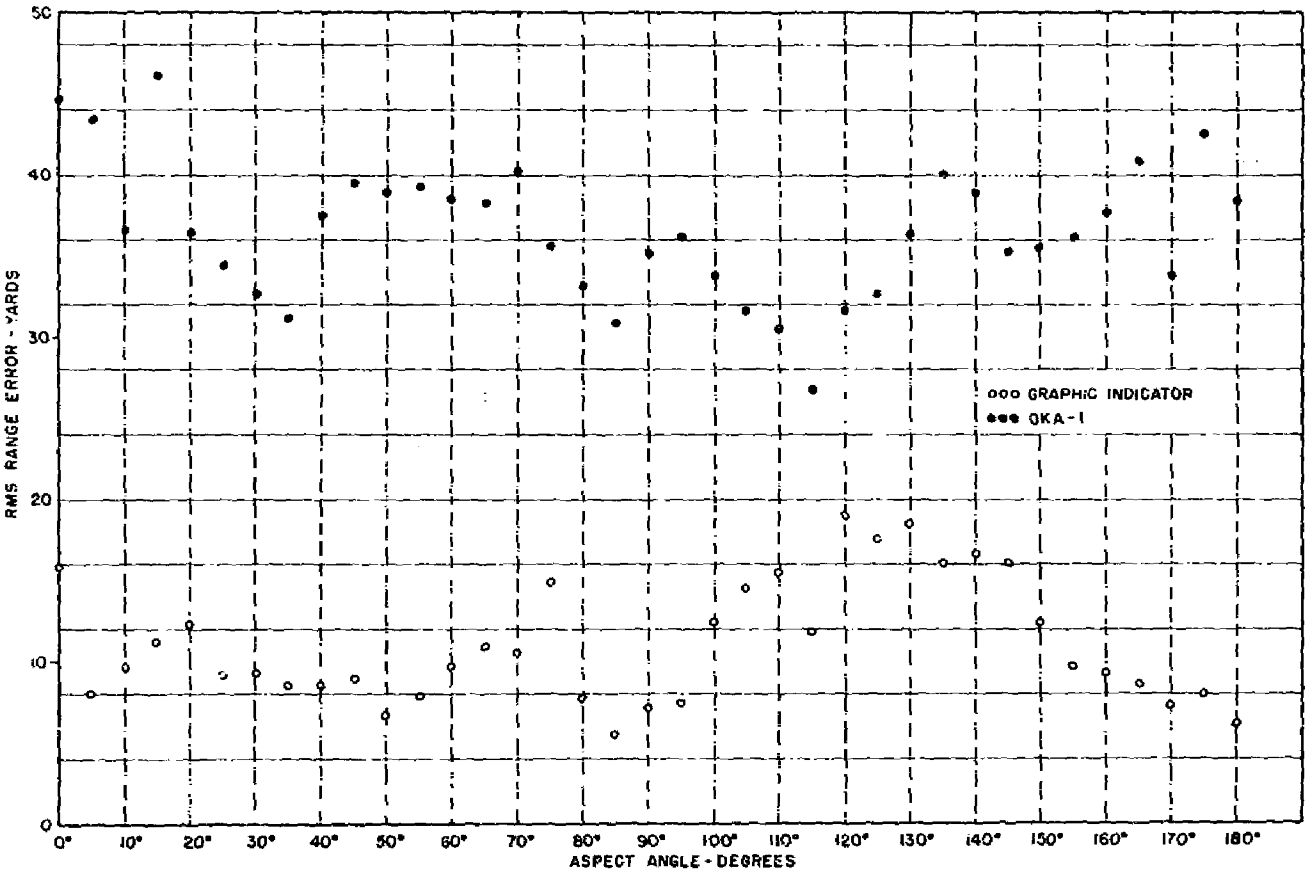

Fig. 16 - Aspect dependence of rms range error. Periscope range derived from Target Locator range as standard.

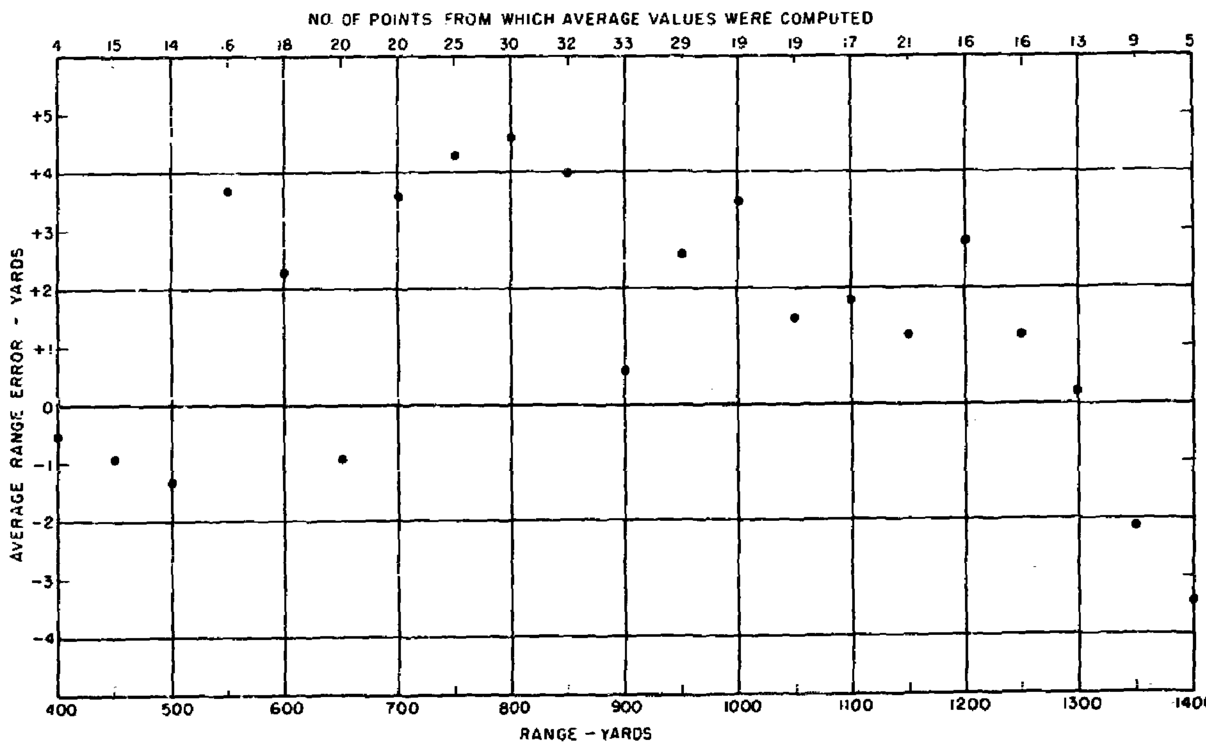

Fig. 17 - Range dependence of average range error for Graphic Indicator data. Periscope range derived from Target Locator range as standard.

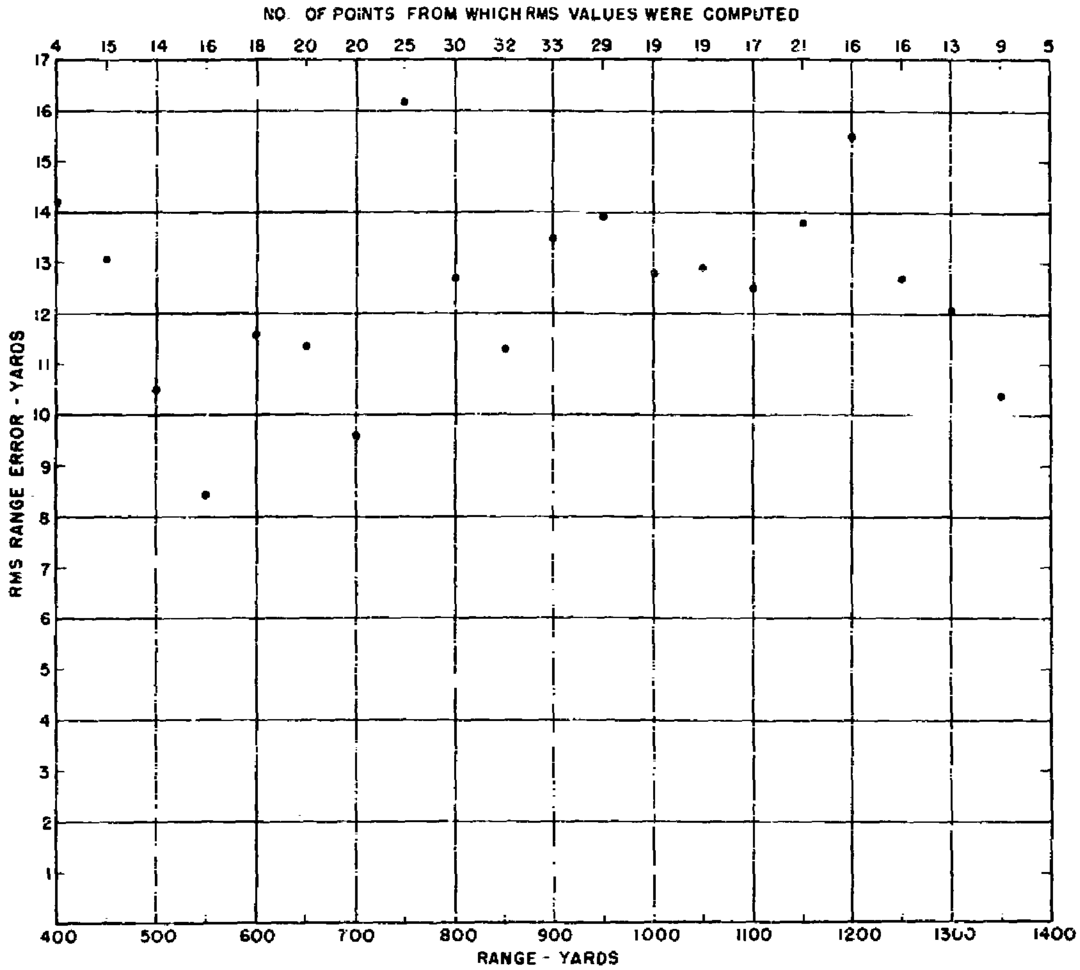

Fig. 18 - Range dependence of rms-range error for Graphic Indicator. Periscope range derived from Target Locator range as standard.

The rate-aided tracking feature incorporated in the Graphic Indicator range unit generates a range equal to the last measured range plus a time integral of the last measured range rate. Evaluation of this feature has been qualitative in nature. The "aid-to-tracking" feature was used in all the tests referred to in this report, and it is the opinion of all the participating operators that this feature contributes greatly to the ease, smoothness, and accuracy with which a target can be tracked in range. In instances when sonar contact was lost for several pings, the range-rate integrator continued to generate a range which proved to be very close to the actual range when contact was regained. This contributed greatly to the smoothness and speed with which the operator could correct the range. It was noted during a high-speed run, with the target making 12 knots and presenting a stern aspect, that the Graphic Indicator presentation was such that the target could be easily tracked throughout the run, whereas considerable difficulty was experienced by the SQS-11A operators in maintaining contact on the target.

In another maneuver while conducting simulated depth-charge attack runs, with the target at a depth of 150 feet, the Graphic Indicator presentation was such that contact was maintained and range measured even after the AN/SQS-11A sonar had lost contact due to short range. In addition, contact was maintained by the Graphic Indicator after the surface vessel had passed over the target.

CONCLUSIONS AND RECOMMENDATIONS

As a result of the analysis of data from these tests of the Sonar Graphic Indicator equipment, it is concluded that sonar range measurements by this method are obtainable with an over-all average error of less than one yard and an rms error of approximately 12 yards. It is also concluded that the dependence of tracking errors on target aspect, target speed, and range is insignificant within present fire-control ranges.

The high precision of range measurement obtained by this method is attributed to:

a. The discrimination between submarine hull and nonhull signal returns,

b. The inherent precision of the range chronometer with associated components, and

c. The ease of operation and smoothness of data output.

In addition, the information from the analysis indicating two initial reflecting regions, one approximately 26 yards forward and the other approximately 36 yards aft of the second periscope, enables the development of an acoustic model of the submarine. Such a model leads to a better understanding of the manner in which sound energy is reflected from a submarine.

It is recommended that a service test equipment, based on the principles and methods employed in the experimental instrumentation discussed herein, be constructed and operationally evaluated for ASW application.

In the application of the principles of this equipment to the construction of operational equipment, simplification should be achieved by measuring the range from the center of the transmitted pulse to the center of the submarine hull signature on the strip display. This modification of measurement technique would essentially eliminate the range correction for aspect, 26 cosα or 36$|\cos\alpha|$, from consideration in the fire-control computation. The range so measured would be to a point very near the center of geometry of the target. Accuracy of range measurements of an equipment with such a modification should be comparable to those achieved during these tests. This recommendation results from the observations, in the data, that the extension of echo signature (in range) was very nearly 62$|\cos\alpha|$ yards.

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* * *

APPENDIX A
Experimental Equipment

DISCUSSION

In order to utilize the Sonar Graphic Indicator and strip display to measure range, it is necessary to mark the target position on the screen by means of a variable time (range) cursor and measure the time delay from the transmitted ping to the cursor. An electronic method for marking the target range was chosen for reasons of accuracy and convenience. To generate such a cursor some form of time-delay mechanism, initiated by the sonar, was required. Several forms of medium-precision electronic-time-delay circuits were tried but did not give the accuracy or linearity desired for a research tool. As a consequence, a high-precision chronometer-type ranging unit, employing digital techniques, was developed. Because range rate was available from the Graphic Indicator, a method of utilizing this quantity as an aid to range tracking was possible.

An experimental digital range unit with rate-aided range tracking was constructed and integrated with the Graphic Indicator and strip display. The entire equipment occupied a space equivalent to two standard six-foot relay racks (Fig. A1), and no attempt was made to engineer the equipment into a smaller unit. Although it was experimental laboratory equipment, it was adequately constructed for use in sea tests.

GRAPHIC INDICATOR WITH STRIP DISPLAY

The Graphic Indicator* (Sonar Receiver, R-404/UQ) and the strip display (Sonar Data Indicator, $Q5_X$†) have been described elsewhere and will not be dealt with in detail in this discussion. A listing of the characteristics of the receiver and reference oscillator is included here since these two items differ slightly from the original Graphic Indicator receiver and reference oscillator.

Receiver Characteristics

a. Tuning range - 19 kc to 50 kc

b. Bandwidth - (3 db points)

   1000 cps at 19 kc
   1300 cps at 25 kc
   2250 cps at 50 kc

c. Input impedance - 500 ohms, balanced

d. Gain - 132 db

e. Signal-to-noise ratio - 2/1 for 0.25-μvolt signal

*Asbury, G. F., Sr., Dixon, T. O., Hurdle, B. G., Mackey, R. J., Jr., and Kohn, E. J., "The Sonar Graphic Indicator," NRL Report 4028 (Secret), August 6, 1952

†"Preliminary Instructions for Operation of Sonar Data Indicator, Units 2 and 3 - $Q5_X$," NRL Memorandum Report 277 (Confidential), March 1, 1954

f. Base clipper - automatic level setting type

g. Output - 5 μsecond pulse, 50-volts positive across 1000-ohm impedance

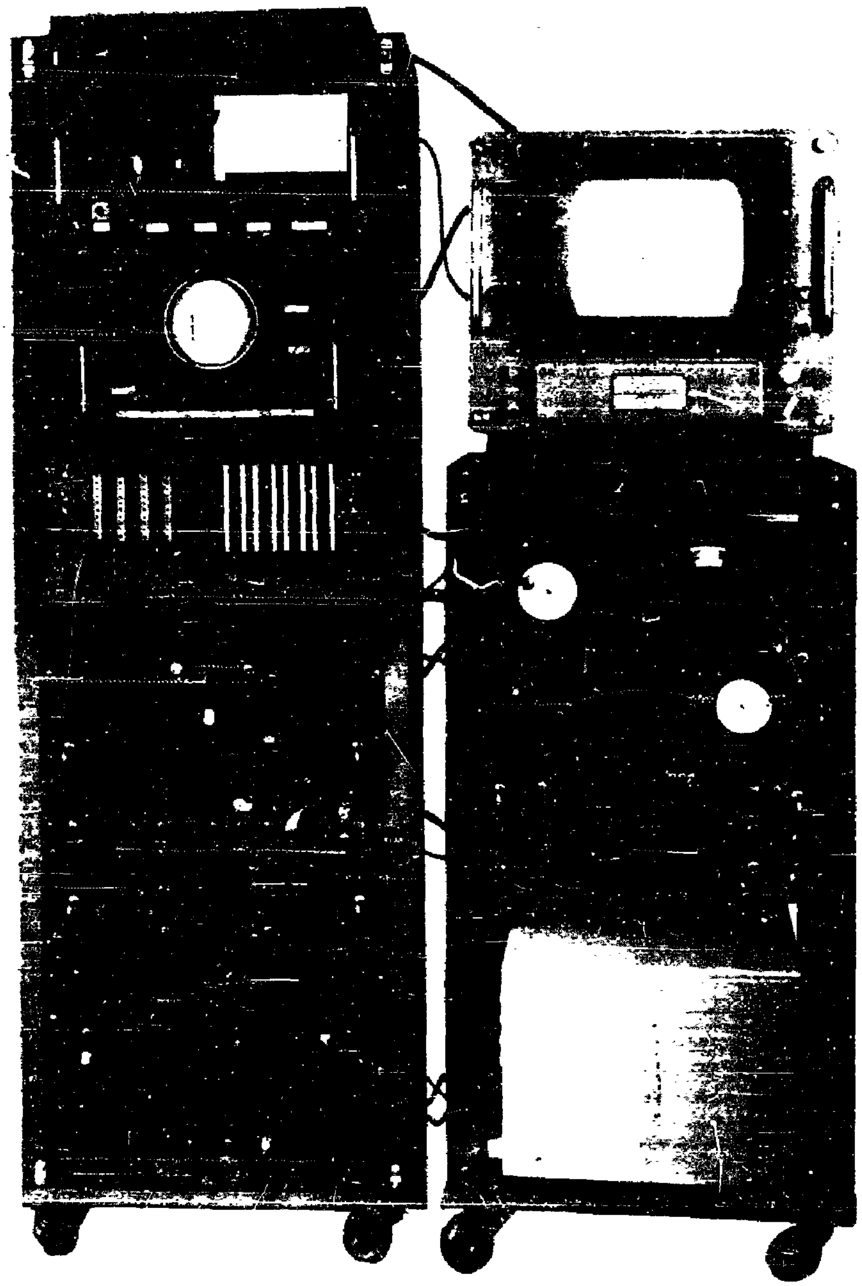

Fig. A1 - Experimental Sonar Graphic Indicator equipment

Reference Oscillator Characteristics

a. Tuning range - 19 kc to 26 kc

b. Range rate - calibration independent of base frequency

RANGE UNIT

Method of Operation

The range unit (Figs. A2 and A3) enables the determination of range by means of an electronic chronometer which measures the propagation time interval between the transmitted sonar ping, and a range cursor placed in coincidence with the received target echo. Target range rate, as measured by the Sonar Graphic Indicator, is converted from a shaft position to a voltage which in turn is used to control an electromechanical integrator affording range corrections as a function of time.

In the sequence of operation, the initiating event is the reception of the sonar synchronizing pulse at the leading edge of the transmitted sonar ping. This pulse is passed to a reset-pulse former for shaping, and then to the four decade counters resetting them to zero. The pulse is also inserted into the time-delay generator which first delays the pulse sufficient time for counter reset to take place and then feeds the pulse to the timing gate. The arrival of the delayed pulse at the timing gate turns it on and allows the sine wave from the range oscillator to pass through to the count-pulse former where it is shaped for insertion into the units decade of the counters. The counters then begin to count each cycle of the range oscillator or each count pulse. As counting progresses each digit of the four decades produces an output of r-f pulses equivalent in length to the time the count is on a particular digit. The outputs from the four decade counters are fed to corresponding positions on the four decade rotary switches. When the count reaches that count set in on the switches, there is a simultaneous output from all switches. Their coincidence is detected in the coincidence gate and a pulse is sent back to the timing gate, cutting it off and stopping the count. Simultaneously, the timing gate transmits a pulse to the range-index-pulse generator where it is processed for mixing with the signal video and application to the Z-axis of the display.

The range is read from a bank of neon lights indicating the position of each of the decade switches. To record range, a pulse is obtained from the range-index-pulse generator for controlling the data camera, thereby photographing an auxiliary bank of range-indication lights each time the range cursor appears.

The position of the four decade range switches (units, tens, hundreds, and thousands of yards) is controlled by the output of a mechanical differential which adds the inputs from the initial range-set (R_0) handwheel and the output of the velocity servo. The velocity servo is controlled by the range-rate-tracking handwheel ($\dot{R}$). In addition, a slew mechanism is provided to rotate rapidly the hundreds and thousands switches independently of the units and tens switches. The slew mechanism is controlled by the front-panel range-slew switch (R_0').

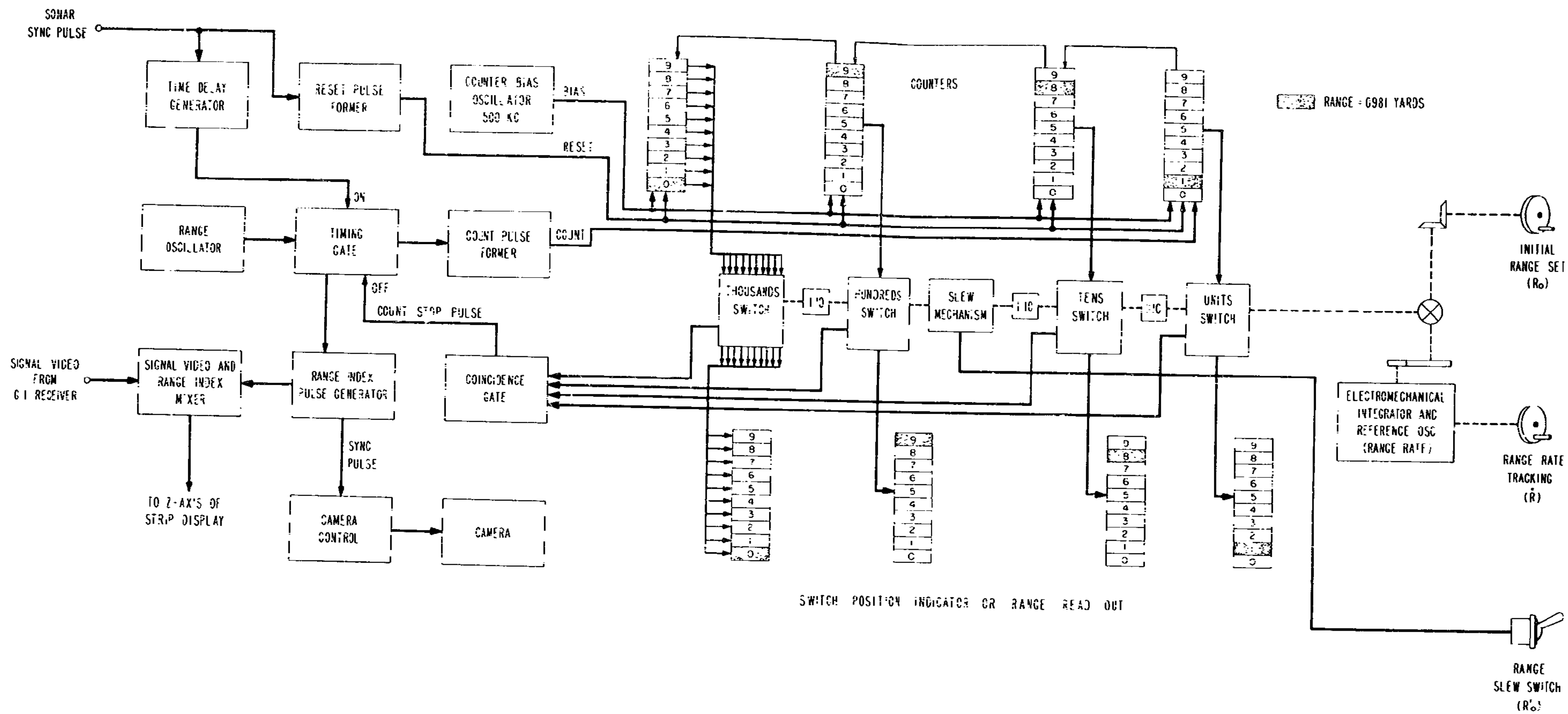

Fig. 2A - Plock diagram of experimental Sonar Graphic Indicator range unit

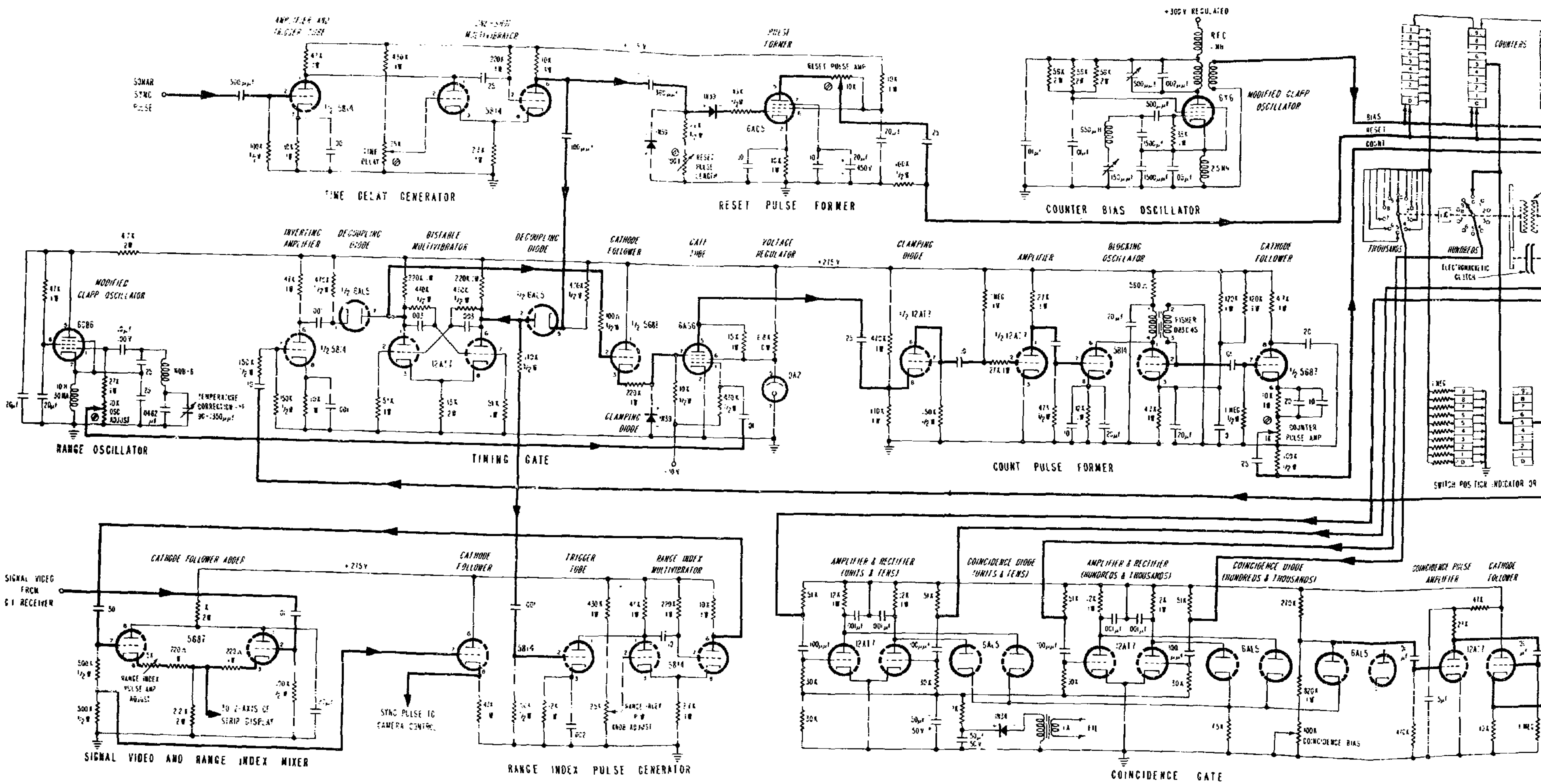

Fig. 3A - Schematic diagram of Sonar Graphic Indicator range unit with rate-aided range tracking

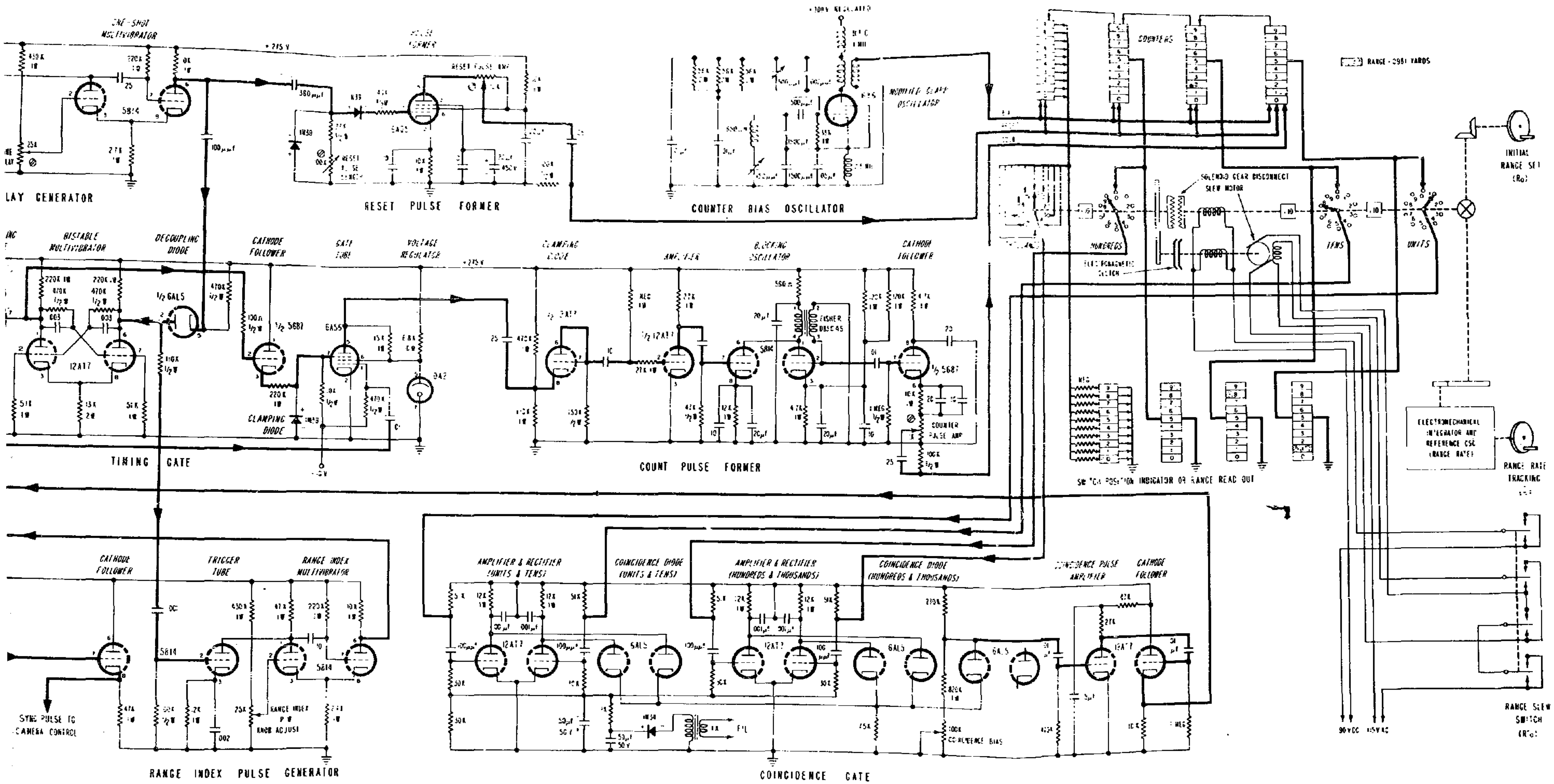

Fig. 3A - Schematic diagram of Sonar Graphic Indicator range unit with rate-aided range tracking

Timing Standard

The timing standard for the range unit is the range oscillator, a modified Clapp oscillator, which may be varied in frequency to compensate for propagation time variations caused by changes in water temperature.* The required period, T, of the oscillator is given by the equation

$$T = 2\frac{\delta R}{C},$$

where

δR is the smallest increment of range to measured (yards), and

C is the velocity of sound in sea water (yards/second).

The multiplier 2 in the above equation takes into account the two way propagation time for echo ranging.

For temperature variations encountered in "normal" sea water, the oscillator frequency has to cover a range from 792.00 cps, for 32°F, to 848.33 cps, for 90°F. Because of the location of the sea test area discussed herein, a frequency range was provided to accommodate temperatures between 73°F and 84°F.

The oscillator stability was such that a 10-percent variation in plate and filament voltages resulted in range errors of approximately ±0.1 yard for a 10-second interval or approximately 8000 yards, while tube changes had virtually no effect on range measurement. Since the least count of the range measurement was ±1.0 yard, the ±0.1-yard error was insignificant.

Time-Delay Generator

The time-delay generator consists of an amplifier and trigger tube, and a one-shot multivibrator. The multivibrator was necessary to insure the proper sequence between the resetting of the decade counters and the "turning on" of the timing gate. The delay between the two events was equivalent to a maximum range error of -0.1 yard.

Count-Pulse Former

Because the particular counters which were used count best on short positive pulses, it was necessary to convert the sine wave from the range oscillator to the desired pulses. This was done by means of a keyed blocking oscillator with a cathode-follower output.

Decade Counters

The decade counters used in the equipment are of the saturable reactor type and contain no vacuum tubes. Reactor excitation is provided by a 500-kc bias oscillator with switching accomplished by the dc pulses mentioned previously. Small neon bulbs indicate individual counts from behind a numbered plastic strip. In operation the counters were

*Del Grosso, V. A., "Velocity of Sound in Sea Water at Zero Depth," NRL Report 4002, June 11, 1952 observed to count during the timing interval and then hold and display the count until the next transmission. The counters have a maximum counting range of 9999. Each of the 40 counter digits is brought out individually to a corresponding switch position on a 10-position rotary switch. The output of any registering digit is in the form of a 500-kc pulse. The length of the r-f pulses from the unit's counter is equivalent to the least count or the period of the range oscillator. The length of the pulses from the succeeding decades is increased by a factor of 10 for each decade.

Range-Selector Switches

The range-selector switches consist of four 10-position rotary switches mechanically connected by means of a Geneva-type 10:1 reduction gear between each switch. For every complete turn of the units switch, the tens switch turns one-tenth turn in a step fashion; the hundreds and thousands switches operate in a like manner. The position of each of the switches is indicated by the switch-position indicator consisting of a bank of dc actuated neon lights similar to those for the counters. A remote set of indicators is provided for photographic recording.

Coincidence Gate

The simultaneous occurrence of the 500-kc signal on the four switching arms of the range-selector switches and, thus, at the input of the coincidence gate, produces a pulse from the cathode-follower output of the gate. Each of the incoming r-f signals is amplified and rectified before insertion into coincidence diodes. The resulting coincidence pulse is amplified and transmitted from the cathode-follower output back to the timing gate to cut it off.

Range-Index-Pulse Generator

When the bistable multivibrator in the timing gate changes its state, a step is transmitted to the range-index-pulse generator, which consists of a trigger tube and a multivibrator. The output pulse from the range-index-pulse generator is mixed with the signal-video pulses from the Graphic Indicator signal-processing channel in a cathode-follower adder, and transmitted to the strip display for insertion in the Z-axis of the crt. The range-index pulse is also transmitted through a cathode follower to provide actuation of the data camera.

Initial Range Set

The initial range set is provided by two controls, the R_0 handwheel and the R_0' slew-switch control. For coarse range-set the R_0' slew-switch control, enabling rapid target-range acquisition, is employed. The slew switch disconnects the mechanical link between the tens and hundreds switches with a solenoid gear disconnect; simultaneously a motor is connected to the hundreds switch shaft by an electromechanical clutch causing the hundreds and thousands switches to be rapidly rotated. Two positions on the slew switch allow a slew "in" and "out" in range. For fine range-set the R_0 handwheel is rotated, at 10 yards per revolution, to drive the units switch. This drive is made through a mechanical differential.

Rate-Aided Tracking

As mentioned previously, range rate, as obtained from the Graphic Indicator, appears as a shaft position and is available for processing for aided tracking. When the range-rate knob $\dot{R}$ is turned, a precision potentiometer (Fig. 4A) ganged with the reference-oscillator range-rate control, is also turned. The output of this potentiometer is a 60-cycle ac voltage varying in amplitude and phase, depending on the magnitude and direction of rotation, respectively. This control voltage is fed to an amplifier that drives the control field of a two-phase servo motor, its speed and direction being determined by the amplitude and phase of the amplified input voltage. A tachometer (induction generator) connected to the shaft of the motor generates an ac voltage proportional to motor speed, which is seriesed with the control voltage at the input of the amplifier. With this feedback arrangement, the motor runs at the speed called for by the control voltage, regardless of variations in power supply, mechanical load, and power frequency. Motor and generator fields, and control signal are all supplied from the same 60-cycle power source.

The motor shaft is connected through reduction gearing and the differential to the units switch, driving it at a speed proportional to range rate. The effect is the same as if the initial range-set handwheel were turned at a constant rate, thus moving the switches at a speed proportional to range rate. By adjusting the voltage across the control potentiometer, a range-rate calibration accurate to the order of ±0.25 knot has been achieved, although for long periods of operation it approaches ±0.5 knot and must be checked frequently to better the ±0.5-knot accuracy.

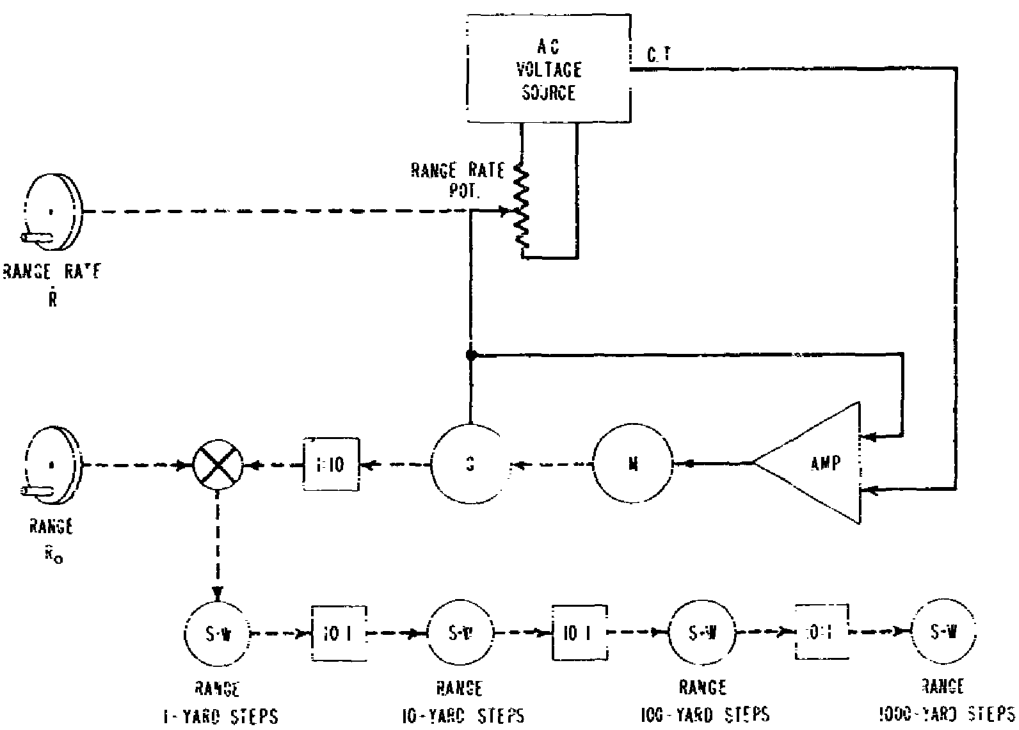

Fig. 4A - Constant velocity servo integrator

Operating Sequence of Range Unit

An example of the operating sequence of the range unit is shown in Figs. 2A and 3A. The range-selector switches are shown positioned at 0981. At the leading edge of the transmitted sonar ping, all the counters are set to zero. At a later time, corresponding to a range of one-tenth yard, the timing gate is turned "on" and the counters begin to count each cycle of the timing oscillator. When the counters reach the count "set in" on the switches, in this example 0981, there is an output from all sw··ches simultaneously. Their coincidence is detected in the coincidence gate to an accuracy of ±1 count or yard. The coincidence gate output turns "off" the timing gate which in turn triggers the one-shot multivibrator generating the range-index pulse, which is used to intensify the screen of the crt to form a bright, vertical cursor on the display. When the timing gate is cut off, the counters display the range of 0981 yard, as illustrated by the shaded digits, and hold the count until another sonar transmission is made.

Accuracy of Range Unit

The range accuracy of the range unit for a single operation (ping) is the sum of the timing-oscillator stability (±0. 1 yard), the coincidence-gate count selection (±1. 0 yard), and the time-delay-generator-multivibrator delay (-0. 1 yard). The timing-oscillator and coincidence-gate errors tend to be averaged out when a statistical number of measurements is made, leaving the errors in range measurement introduced by the range unit insignificant compared to errors introduced by other factors.

* * *

APPENDIX B
Data Analysis

PROCESSING OF DATA

The range data, as read from the 16-mm film, required processing before it could be analyzed. Aspect and range-translation corrections were required in order to refer the ranges, as measured by different pieces of equipment, to the reference points on the surface vessel and target. The SQS-11 transducer in the surface vessel and the second periscope of the target submarine were chosen as reference points. These points were selected because they required the fewest corrections to be made to the data. The SQS-11 Sonar, Target Locator, and Graphic Indicator used the sonar transducer on the surface vessel as the reference point, therefore, no corrections were required at the surface vessel for the ranges measured by these equipments. The radar range measurements were not used in the analysis because malfunctioning of the remote indicator system introduced variable errors into the range transmitted to the remote panels from which the data were photographed.

The transponder equipment for the target locator utilized the QB transducer, located 17 yards forward of the second periscope on the BARB, and the top-side WFA transducer, located 25 yards forward of the second periscope on the QUILLBACK. To refer the Target Locator range to the second periscope, a correction of 17 cosα yards, where α is the aspect angle, was added to the measured range of the BARB, and 25 cosα yards was added to the measured range of the QUILLBACK. Thus, the range to the periscope, as computed from the Target Locator data, became the standard range.

After the sea tests had been made, it was discovered that there was a small error in the Bathythermograph calibration. The Bathythermograph read approximately 1-1/2°F high in the temperature range of interest. The Target Locator and Graphic Indicator range unit were adjusted for water temperature to match the BT temperature prior to the discovery of the error, thus, the calibration error caused the measured ranges in this case to be 0. 28 percent too long. Since the Graphic Indicator range unit and the Target Locator are affected equally by errors in water temperature measurement, the difference between Target Locator range and Graphic Indicator range is essentially unaffected by temperature changes.

PLOTTING

The periscope range (derived from the Target Locator data), Graphic Indicator range, and OKA-1 range were plotted vs. time for each of the 1[illegible] runs analyzed. Scales of two yards per millimeter and one second per millimeter were used for all plots. Aspect angle for each run were plotted as a function of time on the same graph as the range data. For purposes of stastical analysis, the difference between the periscope range and each of the other two ranges was tabulated at increments of five degrees of aspect, and also at increments of 50 yards of range.

STATISTICAL PROCEDURE

ΔR vs. Aspect

In processing data for the determination of the apparent initial reflection points, the first step was the acquisition of the ΔR vs. aspect function. ΔR is the difference between the periscope range, derived from the Target Locator range, and faired values of the Graphic Indicator range. An estimated 80 percent of the total Graphic Indicator range data from the 13 runs was used, representing only the smoothest and most reliable portion of the data.

No dissymmetry of the data from the port and starboard sides of the submarine was found so that data from equal angles either side of zero aspect were combined. Mean values of ΔR were computed for each 5-degree increment of aspect. Standard deviations were computed to indicate dispersion about the mean.

A measure of the validity of the mean values of ΔR is given by the confidence interval. The confidence interval is an interval taken symmetrically about the computed mean and having limits such that there is a certain probability that this interval will include the true mean. The limits of the confidence interval were computed to have values such that the probability that the interval would cover the true mean would be 0.9. In other words, in nine cases out of ten the interval so constructed would include the true mean. The true mean is the hypothetical value that would be the mean of an infinite number of ΔR measurements at a given angle of aspect. It is assumed here that if an infinite number of measurements were made, the ΔR's would have a normal distribution. The following is a sample computation of the mean, standard deviation, and confidence interval at one aspect angle.

> Ninteen values of ΔR were available at the aspect angle of 35°, all of which were positive because the periscope range was longer than the Graphic Indicator range in each case. The sum of the ΔR's was 368 yards. The mean value of ΔR was therefore 19.4 yards. (This value is plotted in Fig. 5.) The difference between ΔR and the mean was then determined for each of the 19 points. The sum of the squares of these difference values was 1224 and therefore the standard deviation $\sigma = 8.0$ yards.
>
> The confidence interval is the region $\pm d$ about the computed mean where $d = t_{0.1}\ \sigma/\sqrt{n-1}$. Here σ is the standard deviation, n is the number of points of data, and $t_{0.1}$ is the 10-percent level of the t distribution as proposed by W. S. Gossett.* Values of $t_{0.1}$ were obtained from Fisher's Table for the distribution of t for certain probability levels.* The value of $t_{0.1}$ for $n = 19$ is given as 1.729, and therefore $d = 1.73 \times 8.0/\sqrt{18} = 3.3$ yards. This is the value that is plotted in Fig. 6. The 90-percent confidence interval for the aspect angle of 35° is therefore the region bounded by ±3.3 yards about 19.4 yards, i.e., 16.1 to 22.7 yards.

Range-Tracking Errors as a Function of Aspect

In order to evaluate the range-tracking accuracy achievable with the equipment, average and rms range errors were computed. For comparison purposes, both average and rms errors were computed for the Sonar Graphic Indicator and OKA-1 data relative

*Peters, C. C., and VanVoorhis, W. R., "Statistical Procedures and Their Mathematical Bases," New York: McGraw-Hill, 1940 to the standard-range data. Since the OKA-1 operator tracked the leading edge of the target as did the Graphic Indicator operator, the same aspect-dependent correction could be added to both ranges. So as to remove the aspect dependency of range, the Graphic Indicator range and the OKA-1 range were increased by 28 $\cos\alpha$ yards for aspects between 0° and 90°, and by $36|\cos\alpha|$ yards for aspects between 90° and 180°. The corrections were limited to a minimum of two yards at aspect near 90° to allow for the radius of the submarine at the near beam aspects. Thus, after removal of the aspect dependency, differences between Graphic Indicator range and the standard range, and between OKA-1 range and standard range, represent the tracking errors in the respective equipments.

Average and rms range errors were computed on an individual run basis as shown in Table 3. An example of the error computation for Run A-1 is as follows:

> There were 30 points of the processed data read at 5° increments of aspect in this run. The positive errors totaled 116 yards and the negative errors totaled 153 yards for an average error of -1.2 yards. The sum of the squares of the errors totaled 3422, yielding an rms error of 10.7 yards.

To obtain the over-all average error (Table 4), the sum of the errors from all the runs was divided by the total number of error measurements. Similarly the over-all rms error was computed from the total number of points without regard to the runs from which they were obtained.

Average and rms range errors were computed and plotted as a function of aspect as shown in Figs. 15 and 16.

In addition, Graphic Indicator average and rms errors as a function of range (Figs. 17 and 18) were computed as above with the exception that errors were taken at increments of 50 yards of range instead of 5° aspect intervals.

In processing the error data, faired curves through the consistent parts of the Target Locator range data were used to eliminate obviously erroneous points caused by premature triggering of the equipment by noise bursts. The Graphic Indicator and OKA-1 range data were not faired except to interpolate between data points, and none were discarded.

* * *

APPENDIX C
Services

Commander Operational Development Force has provided the aid listed below for Phase II of Assist Project Bu/S221/S67, during the period 19 to 23 October 1953.

Vessels:

USS SAUFLEY (EDDE-465) - 5 days

USS BARB (SS-220) - 4 days

USS QUILLBACK (SS-424) - 1 day

Equipment:

Target Locator

Data Panels

Photographic equipment

Personnel:

Project officer and personnel for operating Target Locator and Data Panels

Photographic services:

Processing of all data film acquired during the exercise.

* * *

DISTRIBUTION

CNO		
Attn:	Op-03D	1
	Op-31	1
	Op-311	1
	Op-312	1
	Op-316	1
	Op-34	1
	Op-32	1
	Op-371	1
	Op-373	1
	Op-374	1
	Op-421	1
	Op-45	1
BuShips		
Attn:	Code 845	2
	Code 846	1
	Code 848	1
BuOrd		
Attn:	Code Re4b	2
ONR		
Attn:	Code 411	1
	Code 416	1
	Code 427	1
	Code 463	1
	Code 466	1
BuAer		1
USNUSL		2
USNEL		
Attn:	Library	2
USNOL		1
USNOTS		
Attn:	Technical Library	1
USNPGS		1
USNATC		
Attn:	Electronics Test	1
USNEES		1

USNADC	1
WHOI Attn: C. D. Iselin	1
ComSubDevGpTWO	1
ComSubDivELEVEN	1
CinC PAC	1
CinC Lant	1
ComCruDesPac	1
USNMDL	1
ComDesLant	1
ComSubPac	2
ComSubLant	2
ComSubRon 1	1
ComSubRon 6	1
ComSubRon 4	1
ComSubRon 12	1
ComSubDevGru 2	2
Fleet Sonar School, Key West	2
Fleet Sonar School, San Diego	2
ComOpDevFor	1
ComSurAntiSubDevDet	2
ComHukLant	2
ComTraComdLant	1
ComTraComdPac	1
Special Devices Center	1
USNUSRL	1
OCSigO Attn: Ch. Eng. and Tech. Div., SIGET	1

SCEL Attn: SCEL Liaison Office	3
Office of the Asst. Secretary of Defense (R&D) Attn: Technical Library Branch	2
Pennsylvania State College Attn: ORL, Navy Representative	1
University of Texas Attn: Defense Research Laboratory, Dr. C. Paul Boner	1
MIT Attn: Dr. Richard Bolt, Acoustics Lab.	1
Yale University Attn: Prof. L. W. McKeehan	1
Columbia University Attn: Dr. Eugene Booth, Dobbs Ferry, N. Y.	1
Brown University Attn: Prof. R. B. Lindsay	1
DTMB, Mr. W. F. Curtis	1
Marine Physical Institute Attn: Dr. Carl Eckart	1
Harvard University Attn: Dr. F. V. Hunt	1
Scripps Institute of Oceanography Attn: Roger Ravelle	1
Hydrographic Office	1
National Research Council Attn: Undersea Warfare Comm.	1
Bell Telephone Laboratory, Murray Hill, N. J. Attn: Dr. W. Kock	1
ASTIA Attn: DSC-SD	5

* * *

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Naval Research Laboratory. Report 4629 [CONF.].
MEASUREMENT OF SONAR RANGE EMPLOYING GRAPHIC INDICATOR METHODS [UNCLASSIFIED TITLE], by, R. H. Ferris, B. G. Hurdle, R. J. Mackey, Jr., and K. P. Thompson. 47 pp. & figs., November 30, 1955.

The Sonar Indicator in conjunction with a standard echo-ranging sonar provides range rate by doppler measurements. It also provides discernible discrimination because of phase coherence or doppler difference between the hull echo of the target and reverberation or wake return. To utilize these features for more accurate sonar range measurements, an experimental equipment has been constructed. This equipment consists of a Graphic Indicator with strip display and a range unit providing digital range indication and rate-aided range tracking.

The range unit consists of an electronic chronometer which measures the time interval between the projected sonar pulse and the appearance of an electronic range cursor which can be positioned in coincidence

CONFIDENTIAL (Over)

1. Sonar - Range - Measurement
2. Sonar Graphic Indicators - Application

I. Ferris, R. H.
II. Hurdle, B. G.
III. Mackey, R.J., Jr.
IV. Thompson, K. P.

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Evaluation tests of the experimental equipment were conducted using a destroyer and target submarine. The vessels participated in a series of maneuvers designed to present the target at all aspects for a number of combinations of speed, depth, range, range rate, and range acceleration. Approximately 100,000 items of data including range, range rate, bearing, ship's speed, aspect, and other variables were photographically recorded.

Data obtained from these tests yielded information as to the accuracy of measurement by the Sonar Graphic indicator method, and produces evidence leading to a better understanding of a submarine as a sound reflector. Analysis of data indicated the experimental equipment capable of measuring range with an average error of less than one yard and an rms error of approximately 12 yards. It was also observed that rate-aided tracking considerably enhanced the operator's ability to track the target in range.

The analysis of range data as a function of target aspect permitted the development of an acoustic model of the submarine, a reflecting body approximately 62 yards in length with a lateral dimension of 5 yards.

[Confidential abstract]

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The analysis of range data as a function of target aspect permitted the development of an acoustic model of the submarine, a reflecting body approximately 62 yards in length with a lateral dimension of 5 yards.

[Confidential abstract]

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[Confidential abstract]

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The analysis of range data as a function of target aspect permitted the development of an acoustic model of the submarine, a reflecting body approximately 62 yards in length with a lateral dimension of 5 yards.

[Confidential abstract]

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UNITED STATES GOVERNMENT

memorandum

7103/112

DATE: 22 October 1996

FROM: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

TO: Code 1221.1

AD-083199

VIA: Code 7100

REF: (a) NRL Confidential Report #4629 by R.H. Ferris et al, Nov. 30, 1955 (U)

1. Reference (a) is the practical demonstration of the measurement of sonar range employing Graphic Indicator Methods. The Sonar Graphic Indicator is a method of measuring the phase of a sonar signal on a cycle-to-cycle basis and displaying it on a cathode ray screen. The phase pattern of the signal is used for classification and for measuring the speed, via the Doppler shift, and range of the target.

2. The AN/BQA-3 was the practical utilization of this technology. The AN-BQA-3 has not been in service in submarines for at least ten years, this technology being superseded.

3. Based on the above, it is recommended that reference (a) be declassified with no restrictions.

Burton G. Hurdle

BURTON G. HURDLE
Acoustics Division

CONCUR:

J.B. Palmer for 10/22/96

EDWARD R. FRANCHI Date
Superintendent
Acoustics Division

~~DECLASSIFIED on 23 OCT 96~~

Completed 2-7-2000
B.W.

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(REV). 1-80)
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5010-114